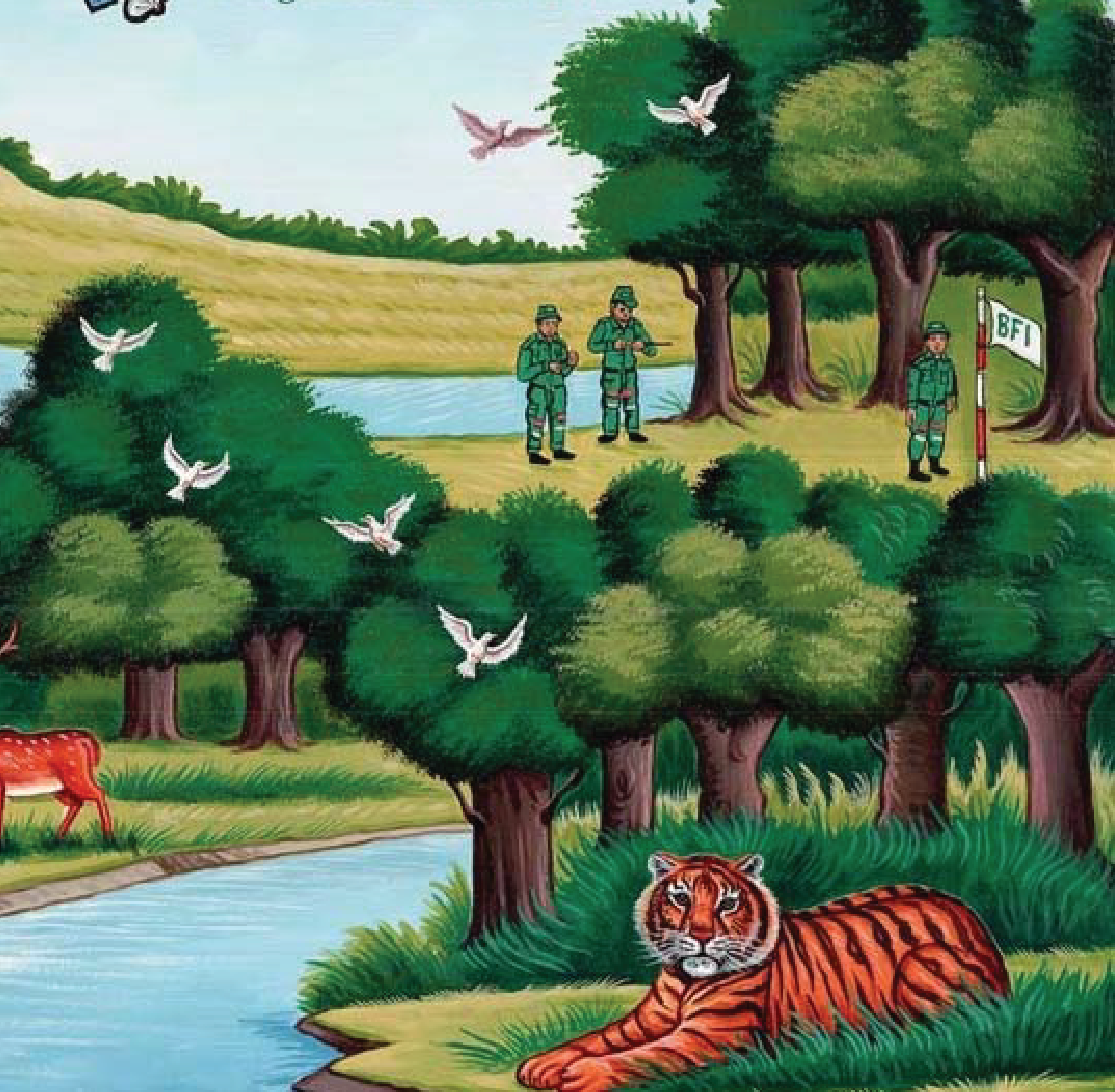
Tree and Forest Resources of Bangladesh

Report on the Bangladesh Forest Inventory



Tree and Forest Resources of Bangladesh

Report on the Bangladesh Forest Inventory

Prepared and published by Forest Department, Ministry of Environment, Forest and Climate Change, 2020

Mangrove forest, The Sundarban ©*FD*

Tree and Forest Resources of Bangladesh

Report on the Bangladesh Forest Inventory

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Foreword

The entire world is looking at forest ecosystems for providing solutions to the adverse impacts of climate change and ensuring the ecological security of the world. Forest ecosystems are dynamic in nature and so require regular monitoring of changes in order to ensure balance between its conservation and development. It gives me great pleasure to note that Bangladesh Forest Department has fulfilled this national need by carrying out first cycle of the inventory from 2015 to 2019 through the project “Strengthening National Forest Inventory and Satellite Land Monitoring System in support of REDD+ in Bangladesh“ technically supported by Food and Agriculture Organization of the United Nations (FAO) and financially assisted by the United Agency for International Development (USAID).

This National Forest Inventory has provided qualitative and quantitative information at the national level, including information on forest growing stock, carbon accounting and other forestry parameters which are not only important to forestry professionals but also to policy makers, planners, researchers, academicians, non-government organizations, community based organizations, etc. having interest in the conservation of forest resources. All these forestry statistics have provided us with a comprehensive picture of our forest resources that allows us to understand these resources and to inform national plans and strategies for balancing sustainable development with natural resource conservation, in particular the Sustainable Development Goal 15 - Life on Land.

I am delighted to note that Bangladesh Forest Department has proved its professional competence in the assessment of forest resources as well as forest cover mapping by using satellite-based land monitoring system, the concept of which is in accordance with the Hon’ble Prime Minister’s vision of “Digital Bangladesh”. I hope that Forest Department will continue to strive making use of advanced remote sensing-based technologies consistent with changing times to provide more comprehensive information for sustainable management of forest resources in the country.I am confident that Bangladesh Forest Department will be able to pursue periodic forest inventory to monitor the changes in our forest resources for sustainable utilization without compromising our effort on conservation.

I am happy to note that this inventory has included trees outside the forest which are major sources of meeting the local demands of timber, fuel wood and fodder. The forest statistics and other information produced by this National Forest Inventory will be widely used in forest policy making, forest management planning, planning of forest industry investments, assessing sustainability of forestry, evaluation of greenhouse gas emissions and changes in carbon storage and research. Moreover, this assessment will make significant contribution towards international commitments by reporting and complying various requirements under Global Forest Resource Assessment, REDD+, UNFCCC, UNCCD, CBD etc.

I am thankful to the USAID and FAO for their continued assistance and support. I express my deep appreciation to the Chief Conservator of Forests and his team for engaging in this endeavour, and for their dedicated efforts, devotion and hard work in successfully completing the inventory to bring about this highly useful and informative report. My hope is this effort will provide the robust information to decision makers for sustainable forest management and conservation in the country.

Md. Shahab Uddin, MP
Minister
Ministry of Environment, Forest and Climate Change

Message

National forest inventories have gained global importance and momentum with countries striving to monitor their forest resources with the intention to generate reliable estimates of the country's tree and forest resources, which will have a long-term impact on improving the management, conservation and benefits from trees and forests. Reliable and up-to-date information on the state of forest resources is crucial for supporting policy formulation, strategic planning, financial investment and sustainable forest management. To generate this information, Bangladesh Forest Department under the Ministry of Environment, Forest and Climate Change implemented the project "Strengthening National Forest Inventory and Satellite Land Monitoring System in support of REDD+ in Bangladesh"from 2015 to 2019 with financial support from the USAID and technical support from the FAO of the United Nations. The resulting Bangladesh Forest Inventory (BFI) is a key contribution to the Measurement, Reporting and Verification (MRV) component of the REDD+ mechanism (reducing emissions from deforestation and forest degradation, conservation of existing forest carbon stocks, sustainable forest management and enhancement of forest carbon stocks).

I am delighted to note that the Bangladesh Forest Department successfully applied the latest remote sensing technologies to lead the comprehensive National Forest Monitoring in the country through a dedicated set of forestry professionals. I am confident that the forestry professionals have been able to enhance their capacities in forest resource assessment and so be able to implement forest resource assessments in future.

The successful completion of BFI and the publication of this report is a testimony to our commitment to the management and conservation of the country's forest resources. It is impressive to look at the contributions of various professionals involved with the implementation of the project and preparation of this report, which provides us with an updated understanding of national tree and forest resources. I am thankful to the FAO of the United Nations for providing technical support and to the USAID for financial assistance to implement the BFI project.

Finally, I would like to record my sincere appreciation, in general, to the Forest Department and in particular, to the BFI team and all the stakeholders contributing to the successful and commendable achievement of the project. I hope the information disseminated by this report will be utilized in full extent to all decision makers, planners, academicians, students and other professionals working in the field of natural resource management.

Habibun Nahar

Habibun Nahar
Deputy Minister
Ministry of Environment, Forest and Climate Change

Message

One of the core missions of the Ministry of Environment, Forest and Climate Change (MoEFCC) is to ensure sustainable management of forests through the conservation of eco systems and biodiversity helpful for addressing climate change. At the same time, it seeks to develop forest resources and recognize the socio-economic contribution and community dependence on trees and forests. As the country continues to experience both economic and population growth, it is critically important to have a national forest monitoring system which captures the impacts of expanding industries and other activities for livelihoods on natural resources.

The data collected from national forest inventory is useful to forestry professionals as well as policy makers as it accurately provides multiple functions of forest eco systems. For many years, we had been lacking in establishing are pea table and comprehensive national forest inventory system in Bangladesh required for mapping forest coverage and socio- economic scenario. Now with the implementation of the Bangladesh Forest Inventory (BFI), a system is in place to provide accurate information as to forest and tree coverage in the country with mention of different uses. The system is the main tool in the forestry sector for monitoring progress towards achieving Sustainable Development Goal No.15–Life on Land. It helps adopt appropriate policies and plans related to other national forestry related priorities as well. It is also the basis for Monitoring, Reporting and Verification (MRV) of Reducing Emissions from Deforestation and Forest Degradation (REDD+) activities that maintain and increase terrestrial carbon stocks to address climate change.

I wish to congratulate Bangladesh Forest Department and its partners for their integrated role in successfully implementing the Bangladesh Forest Inventory. With pleasure I endorse this report, an accurate national baseline document which will help us sustainably manage and develop our forest resources in a transparent way. From now on we will be able to confidently take informed decisions as to our plans, policies and projects requiring data of forestry sector. I look forward to have similar future inventories done in a regular interval. Finally, I am delighted to record my appreciation for officials of Forest Department and consultants of FAO for their cordial efforts in producing this national forest inventory document. I would like to urge all the officials of Bangladesh Forest Department to keep going with sincere endeavor, innovation and proactive role to profile forestry as a viable sector for promoting and implementing sustainable forest management in all its dimensions and capturing its contribution to improving human livelihoods as well as poverty reduction in the country.

Ziaul Hasan ndc
Secretary
Ministry of Environment, Forest and Climate Change

Message

Tree and forest resources play an important role to the sustenance and livelihood of many people of Bangladesh, but the sustainability of those resources is threatened by population growth, agriculture land expansion and shifting land tenure. It is essential to monitor trees and forests to inform decision makers about their status and plan strategies and form policies that ensure sustainable use of forestry resources.

This publication was produced to meet the needs of forest managers and policy makers using results from the Bangladesh Forest Inventory (BFI) first cycle (2015-2019). Although the implementation of the inventory was carried out with financial support from USAID and technical support from Food and Agriculture Organization of the United Nations (FAO) and SilvaCarbon, it is anticipated that future inventories will be performed by a fully institutionalized unit within the Forest Department. The data generated from across the country and over multiple inventory cycles will help Forest Department succeed in its goals to effectively monitor and ensure wise stewardship of the country's forest.

This publication gives readers a glimpse of the total inventory process, including its design, protocols, and partnerships. It provides results about tree and forest extent, tree diversity, regeneration status, income for livelihoods and other important indicators of sustainable forest management. The results include quantifying the supply and demand of forest resources, which highlights the relationship between communities and forest and helps in deciding interventions. The report provides relevant information for reaching national targets, including sustainable development goals, and reporting to national and international frameworks. It is with great pleasure that the Forest Department presents the final results of the BFI.

Md. Amir Hosain Chowdhury
Chief Conservator of Forests
Forest Department

Message

USAID
FROM THE AMERICAN PEOPLE

The United States Agency for International Development (USAID) has supported the development of Bangladesh since the country gained independence in 1971. Over this time, Bangladesh has made impressive strides in many sectors, including agriculture, natural resource management, education, and health. These improvements have increased the nation's prosperity, food security, and resilience to natural disasters. USAID is proud of its partnership with the government and people of Bangladesh and we are encouraged by the positive results emerging from investments in development projects.

The Bangladesh Forest Inventory (BFI) is Bangladesh's first comprehensive nationwide, long-term forest monitoring system. The BFI is the culmination of a four-year, $5.6 million commitment by USAID, to support the Government of Bangladesh's priorities in climate change adaptation, biodiversity conservation, and natural resource management. With this tool Bangladesh will be able to make long-term policy decisions regarding trees and forest resources and their contribution to sustainable livelihoods.

Science, technology, and innovation are vitally important to the success of USAID's activities as they have the transformative power to accelerate development impact, improve cost-efficiency, and increase program reach and sustainability. Tools like the BFI strengthen the evidence for building resilience to natural hazards by increasing the quality of research and analytical skills for assessing risk and promoting adaptation, mitigation, and resilience.

USAID is pleased to support the Bangladesh Forest Department to implement the BFI as its long-term forest monitoring system. This comprehensive and innovative system integrates remote sensing, field measurements, and socio-economic survey results which touch on each major need the Forest Department has to assess and improve Bangladesh's forest resources.

USAID continues to support the Government of Bangladesh's efforts to sustainably manage the country's forest resources and looks forward to seeing the Bangladesh Forest Inventory used to enhance these efforts.

Derrick S. Brown
Bangladesh Mission Director
United States Agency for International Development

Message

Food and Agriculture
Organization of the
United Nations

The current state of the world's forests means that sustainable forest management has never been more relevant because trees and forests play such a fundamental role in the global nutrients cycling, carbon sequestration, conservation of biodiversity, and provision of forest products to livelihoods. The message that future prosperity is linked to wise stewardship of natural resources is gaining greater public recognition.

Over the past four decades, FAO has been providing technical support to the Government of Bangladesh as sustainable tree and forest management has increasingly been considered in national plans and strategies. Whether through developing technical capacity or through direct support to implement forest monitoring, FAO is committed to assisting the government to meet its sustainable forestry goals, including its sustainable development goals and 7th five-year plan targets.

Tree and forest monitoring is crucial to provide baseline information to policy makers for planning and guiding interventions. The launch of the Bangladesh Forest Inventory in 2016 was a great achievement towards long-term national monitoring of tree and forest resources. Throughout the first cycle of the Bangladesh Forest Inventory, the Forest Department, especially the RIMS unit, proved its capacity in deploying an innovative system that benefits from the latest technologies and to implement an exemplar national forest monitoring system in Asia.

FAO congratulates the Forest Department for this successful implementation and reiterates its support when needed for sustainable forest management. The knowledge disseminated through this report has the potential to be far reaching and impactful, influencing many sectors outside forestry towards integrated natural resources management.

Robert Simpson
Representative
Food and Agriculture Organization of the United Nations

Acknowledgments

The Bangladesh Forest Inventory was implemented through the project Strengthening National Forest Inventory and Satellite Land Monitoring System in support of REDD+ in Bangladesh. The project was jointly conceived in 2013 by the Forest Department (FD), Food and Agriculture Organization of the United Nations (FAO) and the United States Agency for International Development (USAID). Funding for the project was provided in 2015 by USAID. The overall implementation and coordination of project activities was led by the Resources Information Management System (RIMS) unit in the FD and under the Ministry of Environment, Forest and Climate Change (MoEFCC). Support for day to day activities in coordinating field work, data management, and data analysis was provided jointly by FD and FAO. Further technical support was also provided by SilvaCarbon throughout the project.

This report reflects the inputs and contributions of numerous individuals and entities who each had an important part in the successful completion of the first cycle of the BFI. These contributions are captured in the following tasks and experts listed (in alphabetical order by last name), along with Sections 2.1.2. and 2.1.3 of this report.

Bangladesh Forest Inventory Team *©Falgoonee Kumar Mondal*

List of Acronyms

FYP - Five Year Plan
ACF - Assistant Conservator of Forests
AGB – Above Ground Biomass
AF - Arannayk Foundation
BA – Basal Area
BBS - Bangladesh Bureau of Statistics
BDT – Bangladesh Taka
FD- Forest Department
BFI - Bangladesh Forest Inventory
BGB - Below Ground Biomass
BNH – Bangladesh National Herbarium
CAGB – Carbon in Above Ground Biomass
CBD – Convention on Biological Diversity
CBGB – Carbon in Below Ground Biomass
CCF – Chief Conservator of Forests
CHTRC - Chittagong Hill Tracts Regional Council
C&I - Criteria and Indicator
CIP - Country Investment Plan
CR - Critically Endangered
CZ - Coastal Zone
CWD – Coarse Woody Debris
DAN – Data Analysis
DB - Dead Biomass
DBH - Diameter at Breast Height
DCF - Deputy Conservator of Forests
DCCF – Deputy Chief Conservator of Forests
DU – University of Dhaka
EFCC - Environment, Forestry and Climate Change
EN - Endangered
ES - Ecosystem Services
FAO - Food and Agriculture Organization of the United Nations
FGD - Focused Group Discussion
FRA - Global Forest Resources Assessment
FWD – Fine Woody Debris
GDP - Gross Domestic Product
GIS – Geographic Information System
GoB - Government of Bangladesh
GPS – Global Positioning System
GS – Growing Stock
Ha - Hectare
HH – Household
HTAC – Household Tree Availability Class
HZ - Hill Zone
IFESCU – Institute of Forestry and Environmental Sciences Chittagong University
LCC - Land Cover Class
mill. - Million
MoEFCC – Ministry of Environment, Forest and Climate Change
MRI - Margalef's Richness index
NLCL- National Land Class Legends
LRSB –Land Representation System of Bangladesh
PEI - Pielou's Evenness index
QA/QC - Quality Assurance and Quality Control.
SDGs - Sustainable Development Goals
SDI - Simpson's Dominance index
SE – Standard Error
SFM - Sustainable Forest Management
SOC – Soil Organic Carbon
SRDI – Soil Research and Development Institute
SuZ- Subdarbans Zone
SWDI - Shannon-Wiener Diversity Index
SZ - Sal Zone
UN - United Nations
UNREDD - The United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation
USAID – United States Agency for International Development
USFS – United States Forest Service
VU – Vulnerable
VZ - Village Zone
Yr – Year

Executive Summary

Trees and forests in Bangladesh provide a wealth of resources in the form of nutrition, energy, medicine and materials which local communities heavily depend on. They are also valued for their contribution to soil and water protection, carbon sequestration and many other services. Nonetheless, these resources are under extreme pressure from rapid population growth, land degradation, and expanding industries. While Bangladesh is aspiring to become a higher middle-income country by 2021, sustainably using and conserving these resources is central to the sustainable development of the country.

Tree and Forest Resources of Bangladesh: Report on the Bangladesh Forest Inventory is a publication which summarizes the results of the first cycle of the inventory performed from 2015 to 2019. It includes national scale estimates from a land cover map and satellite land monitoring system, a forest inventory of 1858 plots, and a socio-economic survey of 6400 households. Each provides baseline information for sustainable tree and forest management and conservation. This system allows for stronger monitoring of both forests and Trees Outside Forest (TOF) and will be updated with results from future cycles.

The results of the Bangladesh Forest Inventory (BFI) are aimed to inform national plans and strategies for balancing sustainable development with natural resource conservation, in particular the Sustainable Development Goal 15 - Life on Land (SDG 15). The BFI process can also be intensified and enhanced to meet specific regional purposes. In summary, it is a comprehensive National Forest Monitoring System (NFMS) which applies the latest technologies to ensure reliable estimates of the country's tree and forest resources and will have a long-term impact on improving the management, conservation and benefits from trees and forests.

More than 30 government agencies, universities and NGO's assisted the Forest Department in completing the first cycle of the BFI by contributing to the design, trainings, data collection, data analysis and other components. The United States Agency for International Development (USAID), the Food and Agriculture Organization of the United Nations (FAO) and SilvaCarbon provided technical and financial resources to the process[1].

The following seven criteria embody this vision of sustainable forest management:

1. Forest extent and tree cover changes
2. Biological diversity and conservation
3. Growing stock, biomass and carbon
4. Management and ownership
5. Tree and forest disturbances
6. Support for sustainable forest management
7. Tree and forest services and livelihoods

[1] Other collaborators include US Forest Service, University of Maryland, National Aeronautics and Space Administration (NASA) and French Agricultural Research Centre for International Development (CIRAD).

Criterion 1 - Forest Extent and Tree Cover Changes (Section 3)

In 2015, forest cover in Bangladesh was 1,884,019 ha, or 12.8% of the total country area using the FRA (2018) definition of forest cover[2]. This amounts to 11.7 ha per 1000 people. When only terrestrial land area is considered (i.e. excluding river and lake area), the forest cover is 14.1%. Hill Forest is the largest forest type by area (4.6% of the country area) followed by Shrubs with Scattered Trees (4.2%) and Mangrove Forest (2.7%). Permanent Crops covered half of the country area and, although these areas are primarily used for agriculture, they still have an average tree cover of about 7%. Notable increases of average tree cover occurs within Mangrove Plantation (12% increase), followed by Mangrove Forest (4%) and Rubber Plantation (2%). The highest decreases in tree cover occurs in Plain Land Forest (Sal Forest) (18%), Shifting Cultivation (14%) and Hill Forest (7%).

Criterion 2 - Biological Diversity and Conservation (Section 4)

Biological diversity in terms of number of tree species per land cover is highest in the Hill Forest and Rural Settlements, where each have more than 240 different species. However, 63% of individual trees in the Rural Settlement are introduced species, compared to only 33% in the Hill Forest. Thus, humans are partially responsible for high biological diversity occurring within their own living environment while native tree diversity is preserved more in natural forests. In total, there were 12 threatened species identified in the biophysical inventory, occurring mostly in the Hill zone. At least two species in the Hill zone were determined to be globally Endangered or Critically Endangered (*Aquilaria malaccensis* and *Anisoptera scaphula*) per IUCN's Red List, although their status within Bangladesh was Vulnerable or Unknown.

Criterion 3 - Growing Stock, Biomass and Carbon (Section 5)

Rural settlements are the largest source of the national growing stock volume which is 2.7 times higher than the volume in Forest area, contributing to 50% of the total growing stock. Similarly, bamboo volume in the Rural Settlement is 59% of the total national bamboo stock.

Trees Outside Forest, which include Rural Settlement, contains 66% of the total biomass. The highest biomass density occurs in the Sundarban zone. One fruit species (*Mangifera indica*), one introduced species (*Swietenia mahagoni*), and one mangrove species (*Heritiera fomes*), are the top three species by biomass in the country and comprise 19% of the national biomass. The highest supply of biomass that is usable for fuelwood (i.e. coarse woody debris, fine woody debris, and litter) is from the Hill Forest (3,408 tons biomass, or 33% of the total), but a substantial amount is also foundin Rural Settlement (2,587 tons, or 25%).

[2] The following land cover classes were considered as forest cover: Bamboo Forest, Forest Plantation, Hill Forest, Mangrove Forest, Mangrove Plantation, Plain Land Forest (Sal Forest), Rubber Plantation, Shrubs with scattered trees, Swamp Forest.

The total terrestrial carbon stock (aboveground, belowground, dead wood, litter and 0-30cm soil) is estimated to be 1275.55 million tons. The majority of the country's carbon stock is held in soils to 30cm depth[3] (80.5%), followed by aboveground biomass (15.3%), belowground biomass (3.6%), dead wood biomass (0.5%), and litter biomass (0.1%). Forest areas hold 21.5% of the total carbon stock in the country and Hill forest and Mangrove forest alone hold 9.7% and 5.2% of the total, respectively.

Criterion 4 - Forest Management and Ownership (Section 6)

There are 3.1 million ha of land, or 23.2% of the total area, which have some form of tree and forest management observed by field teams. 48% of the managed land is some form of plantation (general, woodlot, coastal, rubber or strip), while the remaining managed land is mostly agro-forestry, tea garden, or orchard. Households collect most of their tree and forest products from privately owned lands in the form of energy (41% of total households), materials (8%), and nutrition (7%). Those same products are not collected abundantly from FD owned land (e.g. energy is 2% of total households and nutrition is 1%).

Forest land ownership is still being digitally delineated in Bangladesh. Nonetheless, the BFI is a sample of the total land area and may be used to generate proportions of ownership types. Based on this approach, 9.4% of the total land is owned by FD which subsequently held 24.5% of the country's total aboveground carbon stock.

Criterion 5 - Tree and Forest Disturbances (Section 7)

About 32% of the forest area experience some kind of natural disturbance, with landsliding, other erosion, and cyclones being the most common types. In contrast, in TOF the most common disturbance is waterlogging. Disturbance is also assessed through household interviews where respondents overwhelmingly identified cyclones and infrastructure development as major disturbance types. When asked specifically about the reasons for tree cover loss, the respondents mostly identified degradation in the form of overharvesting and tree removals from construction.

Criterion 6 - Support for Forestry Activities (Section 8)

The socio-economic survey revealed that few respondents (1.3%) reported receiving support for sustainable tree and forest management from any organization. Those who did reported receiving free seedlings and trainings on tree planting. For planting purposes, people usually purchase seedlings and plantings materials from local market but in some cases, people receive free seedlings from Forest Department also. Nationally, 43% of the households purchase their own seedlings over the past year (2017 to 2018) and spend an average of 1,015 BDT for those seedlings.

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[3] Soil carbon was determined by LOI without removing carbonates and may yield higher estimates than other methods such as Walkley-Black.

Criterion 7 - Trees and Forests Services and Livelihoods (Section 9)

The socio-econonomic survey revealed that trees and forests are a rich source of materials, energy, nutrition, and income for the majority of households. An estimated 64% of the total population is involved in collecting primary tree and forest products. The total estimated value of the primary tree and forest products collected is 3.07% of the 2017-18's national Gross Domestic Product (GDP) measured in current price. The value of primary forest products collected by households is on average 19,518 BDT/year, mostly contributed in the form of fruit (47%) and energy (40%).

Trees outside Forest supply most of the country's primary tree and forest products. An exception is in the Hill zone, where about 70% of the timber, bamboo, fuelwood, and leaves, and almost half of the fruits, are supplied from Forest area near the households.

The total value of products used for cooking and heating is 202,927 million BDT/year. The value of these products to households in the Hill zone is nearly four times more than the national average (24,476 v. 6,138 BDT/HH/year, respectively). The average cost of buying forest products for cooking and heating purposes is 2,554 BDT/HH/year nationally.

In terms of income, a household in Bangladesh annually earns BDT 9,160 from selling primary tree and forest products which contributed to 1.29% of the 2017-18's national Gross National Income (GNI) measured in current market price. Households belonging to higher income classes earn more from tree and forest products. Nowhere is the total annual income from trees and forests greater than in the Sundarban periphery zone at 29,275 BDT/year, which is 9% of the total income of that zone, earned mainly from selling fishery products.

Section 1:

A New Era for Forest Assessment and Monitoring

BFI field measurement, Tangail *©Falgoonee Kumar Mondal*

A New Era for Forest Assessment and Monitoring

Trees and forests are of immense importance to the world's population due to their role in global nutrient cycles and provision of a wide array of goods and services. An increasing amount of both public interest and political will are directed towards plans and strategies that develop, protect, manage and conserve forest resources. In Bangladesh, trees and forests play a crucial role in the country's plans towards sustainable development. Ideally, these natural resources should be managed in such a way that balances commercial production, food security and sustainable livelihoods with protection of biological diversity, conservation of plant, soil and water resources, and mitigating climate change. Achieving this balance requires innovative and forward-thinking approaches in tree and forest assessment, monitoring, and management.

The BFI participates in a new era of forest assessment and monitoring because it: 1) provides long-term monitoring, 2) is designed to be fully institutionalized, 3) uses multiple sources of information and the latest forest mensuration technologies, and 4) meets the data needs of multiple purposes. In parallel, its conception and implementation involved a wide range of national stakeholders to ensure their engagement and their contribution throughout the process. Despite the simple name, it is more than just a database of tree measurements. It achieves "the technical process of data compilation and analysis of forest resources from a multitude of data sources, including field inventories and remote sensing, to estimate relevant forest characteristics at particular points in time" (FAO 2017b). The BFI not only quantifies benefits from forests and Trees Outside Forest (TOF), it also provides information about their relationships with the people that use them and makes accessible the information to multiple beneficiaries (FAO 2015b). Furthermore, the BFI is designed to be updated through periodic field measurement cycles, which helps meet evolving societal needs. It is the country's national forest monitoring system (NFMS) for providing science-based information to support policies to conserve and sustainably manage forests in Bangladesh.

1.1

Environmental and Social Challenges

As in many countries, deforestation and forest degradation has been occurring in Bangladesh for hundreds of years. The country's forests are heavily used but the ability to restore forests is limited. Although overall tree canopy coverage increased modestly from 2000 to 2014, the natural forest area declined rapidly (Potapov, Siddiqui *et al.* 2017), and there is a persistent widening gap between the demand and supply of forest products (Rahman 2016). There is limited national level information about the status of tree and forest resources to guide local to national forest management and conservation activities.

The growing need of land for human settlement, agriculture, industries, and timber and fuelwood is largely responsible for deforestation and forest degradation (Chowdhury, Costello *et al.* 2016). Most of the forest loss can be attributed to overpopulation, poverty and unemployment, and lack of governance (UN-REDD 2017). Governance impacts all forest types and specifically included problems related to uncertainty in land tenure and lack of capacity to implement forestry related management, policies, and law enforcement. These indirect drivers in turn lead to a suite of direct drivers of deforestation, namely uncontrolled encroachment from industrialization and agriculture, and illegal logging (UN-REDD 2017). Specific direct drivers of forest degradation differ by zone. For example, forests in Sundarban and Coastal zones compete with shrimp farming or suffer from industrial pollution related to shrimp farms, pesticides, and oil spills. On the other hand, forests in the Sal and Hill zones experience intense pressure due to firewood collection, illegal logging, and exotic species (Chowdhury, Costello *et al.* 2016). The Sundarbans are threatened with oil spills from cargo vessels (Aziz and Paul 2015) and increasing numbers of factories and thermal power plants. The waste and pollution generated impact water quality and threaten the mangrove ecosystem (Sarker, Akhand *et al.* 2016).

The impacts of deforestation and forest degradation in Bangladesh often interact with natural disturbances. For example, despite a moratorium on logging lasting from 1989 until 2020, in the Chittagong Hill Tracts, the exploitation of trees has resulted in a substantial loss of forest cover and soil degradation. Removals of timber and poles and shifting cultivation has degraded landscapes, and when coupled with heavy rainfall has led to heavy soil erosion and landsliding (Mahmood and Khan 2010). Furthermore, in low lying areas the impacts of both human and natural disturbances are more severe in Bangladesh than in neighboring countries due to its vulnerable location among major river systems GOB (2015). Rising sea levels in combination with storms and cyclones make coastal areas especially vulnerable. Salinity intrusion, caused by reduced freshwater flow, changing rainfall patterns and growing aquaculture industry could reduce the fresh water supply for people and their crops (Dasgupta, Hossain *et al.* 2014, Dasgupta, Akther Kamal *et al.* 2015).

QA/QC training, Cox's Bazar *©Falgoonee Kumar Mondal*

1.2

Evolution of Forest Assessment

Previous forest policies and inventories reflect the history of how people viewed Bangladesh's natural resources. Beginning in the British colonial period, forest resources of the Indian subcontinent were diverse and seemed to be unlimited. However, the colonial authorities soon took into consideration that British India's forests were not inexhaustible. Although a national level forest inventory was not available until 2005 (MoEF and FAO 2007), there is a 200 years history of forest inventories at the sub-national level. The first inventory was implemented from 1769 to 1773, but it was limited to selected forest areas in Sundarban. Later, various forests inventories were undertaken for the preparation of forest management plans for major forest types (e.g. Mangrove forests in the Sundarban; Hill forests in Chittagong, Cox's Bazar, Sylhet and Chittagong Hill Tracts; Sal forests in Gazipur, Tangail and Mymensingh). These inventories focused on forest area and crude estimates of what is now characterized as growing stock volume. Only recently did inventories begin to include more forest variables for understanding biological diversity and carbon storage. A complete list of past forest inventories in Bangladesh is found in Appendix 1.3.

Garjan forest, Cox's Bazar ©*Matieu Henry*

1.3

The National Forest and Tree Resources Assessment 2005 – 2007

During 2005-2007, the Forest Department implemented the first National Forest Assessment (NFA) which covered both forests and TOF whereas earlier management inventories were confined within the designated forest reserves only (MoEF and FAO 2007). The NFA objective was to capture detailed information about forest resources and land use. It included remote sensing analyses and a ground inventory with 299 sampling plots (referred to as tracts) throughout the country in a systematic design. Further, the inventory enumerated national land use area, growing stock, biodiversity and regeneration, social and economic aspects of forests and trees and biomass and carbon.

Though the NFA has been used for international reporting purposes, its current use for informing and impacting policies is limited as national objectives and the environment sector have shifted to capturing and monitoring changes at both the national and sub-national scales. In addition, although the NFA design was statistically sound at the national scale, it suffered from some key technical limitations. Firstly, the strategy to establish relatively large but fewer plots resulted in an under representation of certain important forest types such as Sal forest and coastal plantation areas which are key strategic forest types for FD. Second, estimations of volume, biomass, and carbon only used one general allometric equation for all tree species. Third, the inventory was not usable for monitoring purposes as the plots could not be relocated to update the information to observe changes over time (Costello, Piazza *et al.* 2016). For these reasons, the NFA was discontinued, leaving a widening gap between the information needed for national forest assessment and what was available.

Box 1 – Comparing BFI and 2005-07 NFA Results

Both the BFI and 2005-07 NFA provide national level estimates of forest area, volume, biomass, carbon, and information about tree and forest socio-economic products and services. Nonetheless, comparsions between the two inventories are complicated because each uses different land cover classification systems, allometric equations, and sampling design and intensity. For example, the choice about which allometric equations to use in an inventory can dramatically alter volume, biomass, and carbon estimates (Duncanson, Huang *et al.* 2017). Additionally, the NFA socio-economic survey did not collect information about the value and income from tree and forest products, but this was the central purpose of the BFI socio-economic survey. In some cases, meaningful comparisons are possible after adjusting the BFI data, for example by using the same volume equation for both datasets. Some comparisons with explanations are included throughout this report and more comparisons are found in Appendix 1.2.

Modhupur Sal forest, Tangail *©Falgoonee Kumar Mondal*

1.4

Establishing Sustainable Goals

A number of national targets, plans and strategies have been developed in Bangladesh and globally that are aimed at achieving both environmental responsibility and economic growth through science-based policy decisions. In September 2015, the UN General Assembly approved 17 Sustainable Development Goals (SDG's) that are meant to link and address societal, economical, and environmental issues. To achieve SDG 15[4], the 7th Five Year Plan (2016-2020) of Bangladesh (7FYP) targets to have productive forest coverage at 20 percent with 70 percent crown density. The 7FYP strategies for achieving the goals include continuing a moratorium on felling trees in natural forests, increasing tree density through 'enrichment planting' and 'assisted natural regeneration', intensification of plantation activities in coastal areas and continuing social forestry programmes (GED 2015).

A five-year (2016-2020) country investment plan (CIP) was also recently developed and endorsed to coordinate the management of the environment, forestry and climate change (EFCC) sectors in the country. This supports the implementation of the National Conservation Strategy of Bangladesh by overcoming challenges related to lack of coordination among ministries. The CIP is a cross-sectoral and whole-of-government investment framework for mobilizing and delivering effective, coordinated, sustainable and country-driven investment programmes in environmental protection, sustainable forest management, climate-change adaptation and mitigation, and environmental governance. The CIP will be monitored on an annual basis to track the impact of investments, identify success stories and challenges, and provide recommendations for improvements (GoB 2017a).

There are several other important policies related to sustainable forest management. For example, the National Forest Policy (Amended) 1994 attempted to bring 20% of the country's land under afforestation programmes by 2015 (GoB 2016). In addition, the Perspective Plan of Bangladesh 2010-2021 aims at increasing the tree coverage on 2.84 million hectares designated for forests (GED 2012). Finally, the vision of the draft National Forestry Policy 2016 is to increase and stabilize its forest cover to at least 20% of the country's geographical area.

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[4] SDG 15 is "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss".

In parallel to the above developments, in March 2018 Bangladesh became eligible to graduate from a Least Developed Country and will officially graduate given the ability to meet certain requirements over the next 6 years. While this is a significant achievement, challenges remain to sustainably manage the country's natural resources while maintaining economic growth.

A national forest monitoring system is potentially a powerful tool for achieving SDG's and related national plans and strategies. However, to truly empower progress towards these goals through science-based decision making, an NFMS needs to go beyond traditional measurements such as merchantable timber volumes. Multi-purpose and multi-resource forest inventories gather information on many different attributes of forests which forest managers and decision makers use for policy formulation, strategic planning, day-to-day management operations and monitoring.

Accessing the plot center, the Sundarban ©*Falgoonee Kumar Mondal*

Section 2:

The Bangladesh Forest Inventory

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).

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[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.

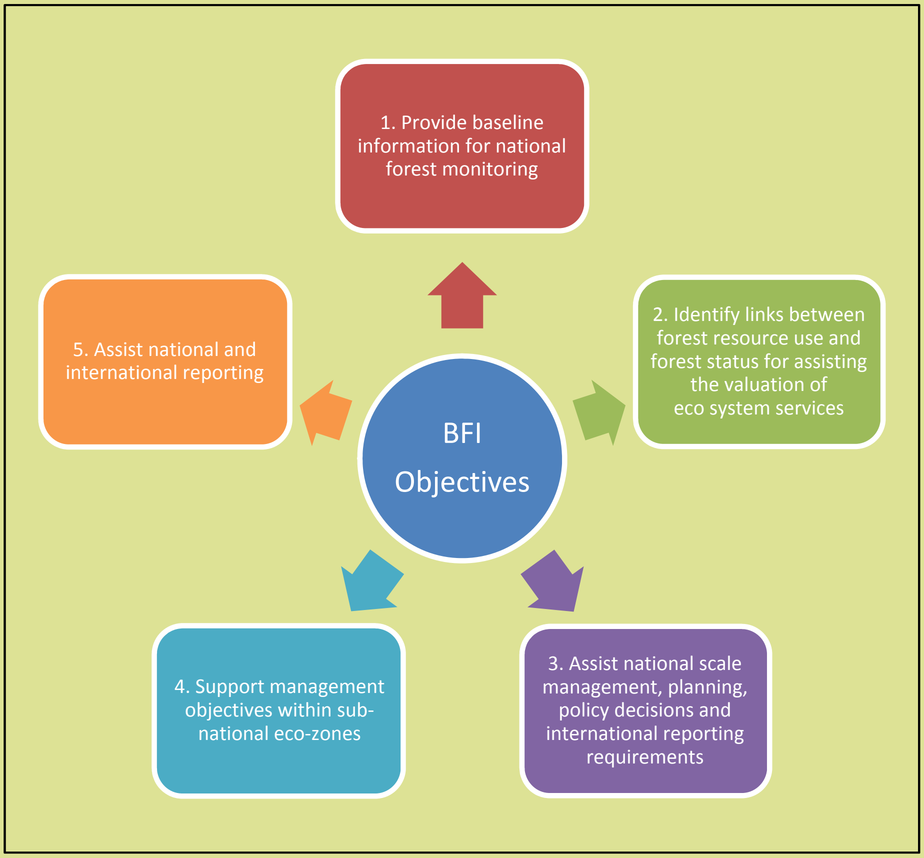


Figure 2.1: Objectives of Bangladesh Forest Inventory

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.

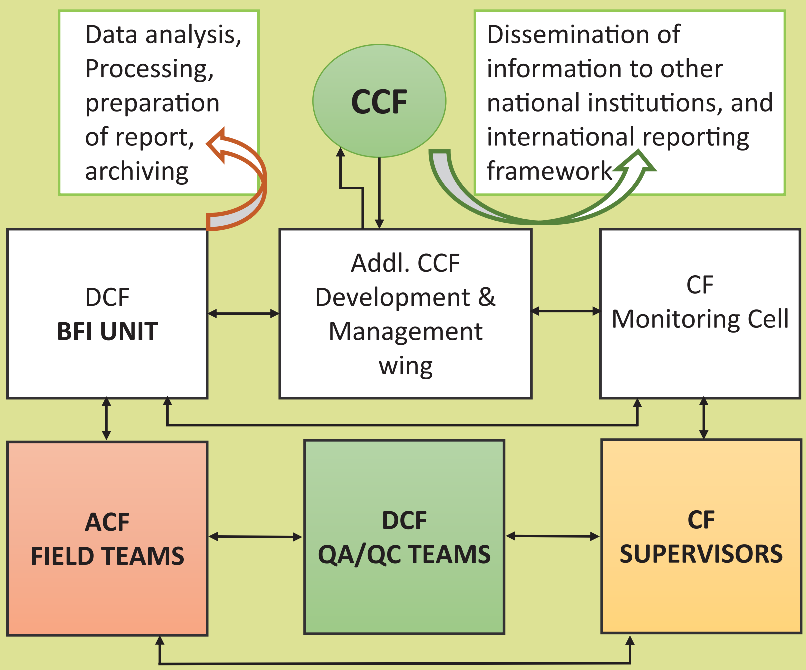


Figure 2.2: Proposed institutional setup for the sustainability of the Bangladesh Forest Inventory (DCF - Deputy Conservator of Forests, CF - Coservator of Forests, ACF - Assistant Conservator of Forests, CCF-Chief Conservator of Forests.

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.

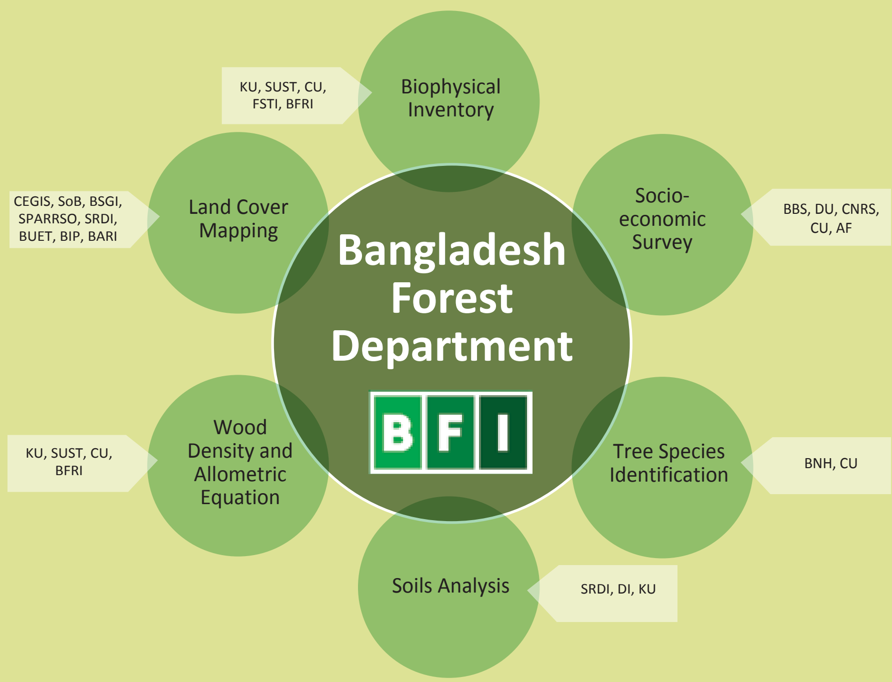


Figure 2.3: Potential collaborations between national public and private entities under different formal agreements to achieve different components of the BFI. The acronym definitions of the insitutions are listed in Table 2.1.

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).

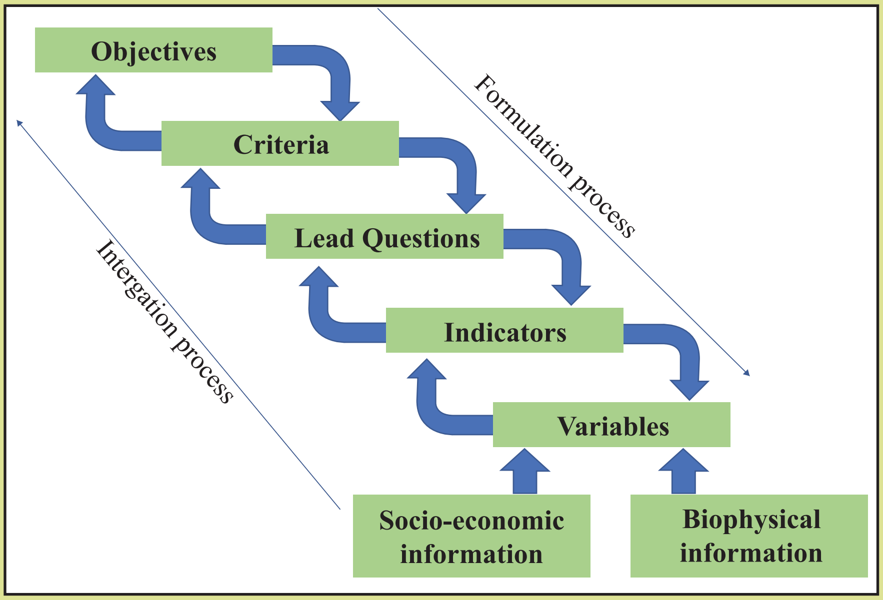


Figure 2.4: The process for determining the variables and indicators to be estimated, which then inform objectives.

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.

Soil sample collection, The Sundarban *©Falgoonee Kumar Mondal*

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 (Figure 2.4).

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 (Figure 2.5). 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.

Watershed management, Bandarban *©Purnata Chakma*

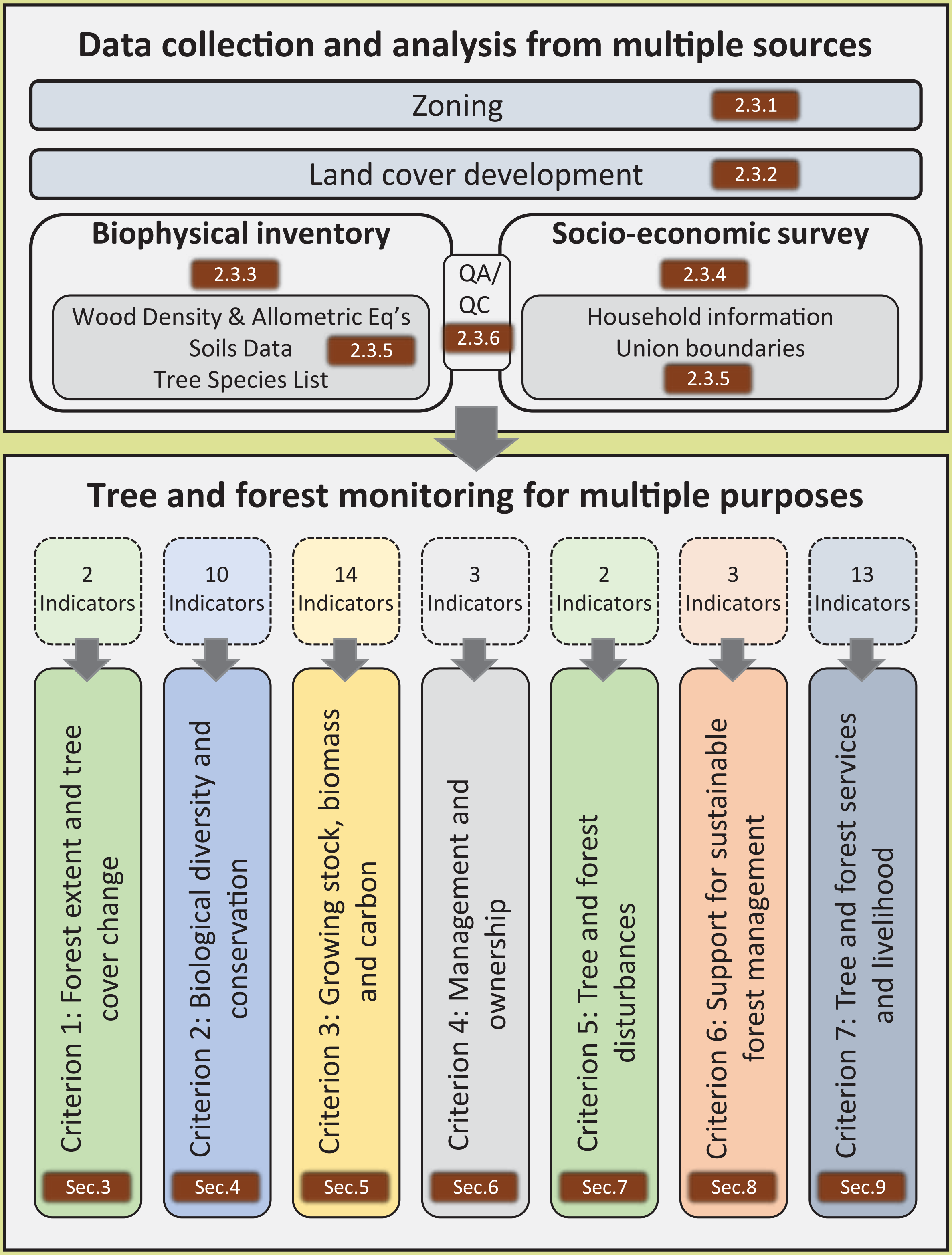
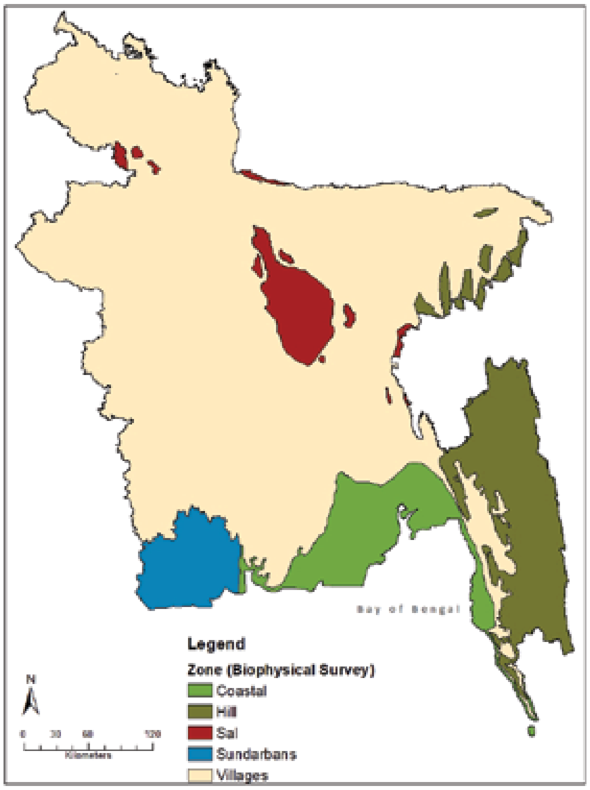


Figure 2.5: Visualization of the the relationships of data from multiple sources for multiple purposes in the BFI process. The numbering corresponds to report sections.

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.



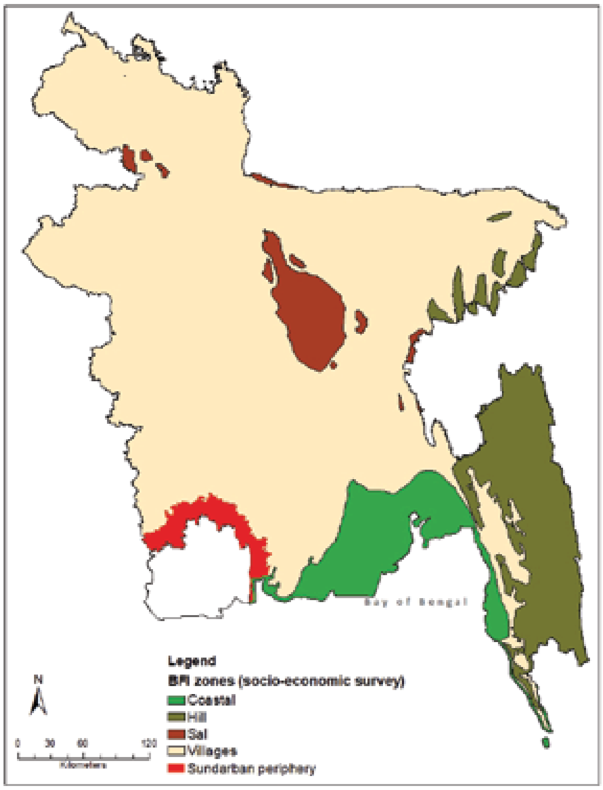


Figure 2.6: Zones of the Bangladesh Forest Inventory. In the left figure are the zones of the biophysical inventory and in the right are the zones of the socio-economic survey.

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 flood plain (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.

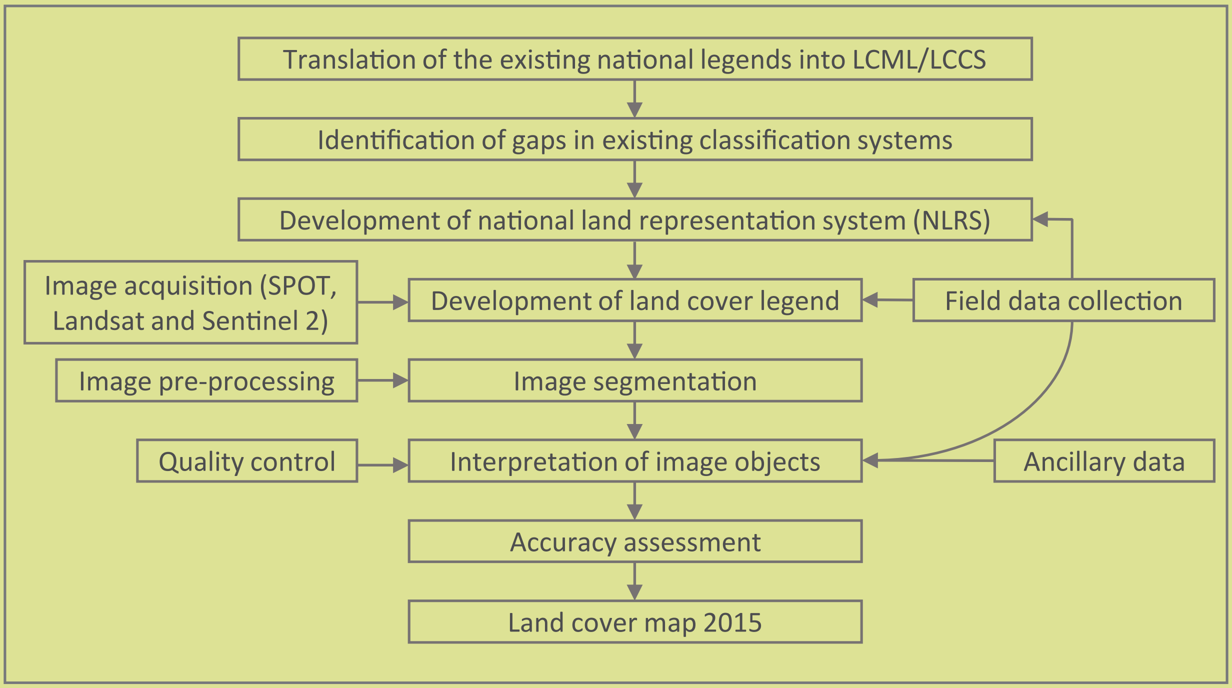


Figure 2.7: Flow diagram of the process for developing the Land Representation System of Bangladesh and Land cover map 2015.

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	0.567	0.006494
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		0.006873

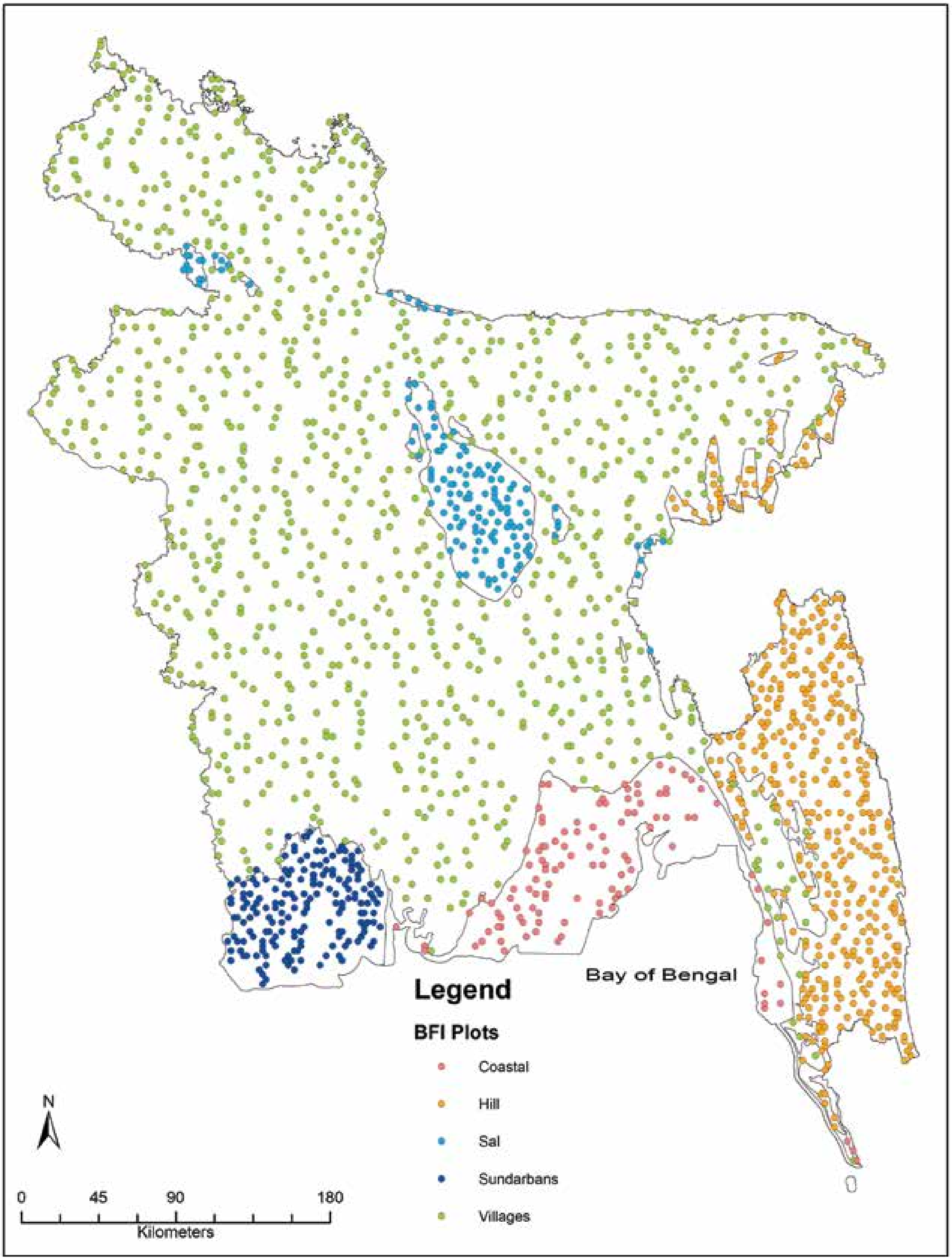


Figure 2.9: The distribution of biophysical inventory plots among five zones in Bangladesh.

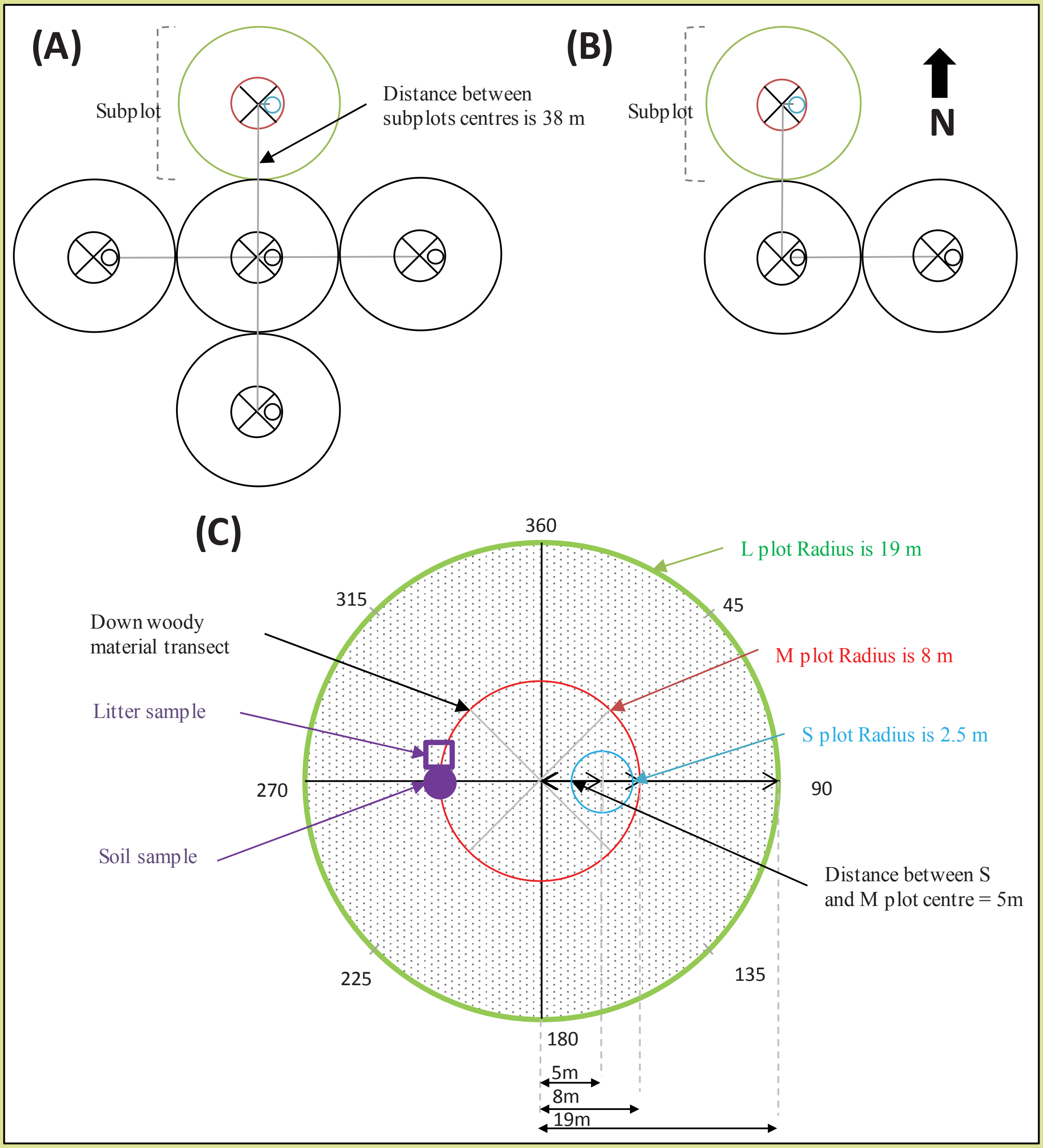


Figure 2.10: (A) Plot design for Hill, Sal, Coastal and Village zones- one plot is composed by five sub-plots, (B) Plot design of Sundarban zone- one plot is composed by three sub-plots. (C) Subplot layout for data collection.

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 teamteam 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.

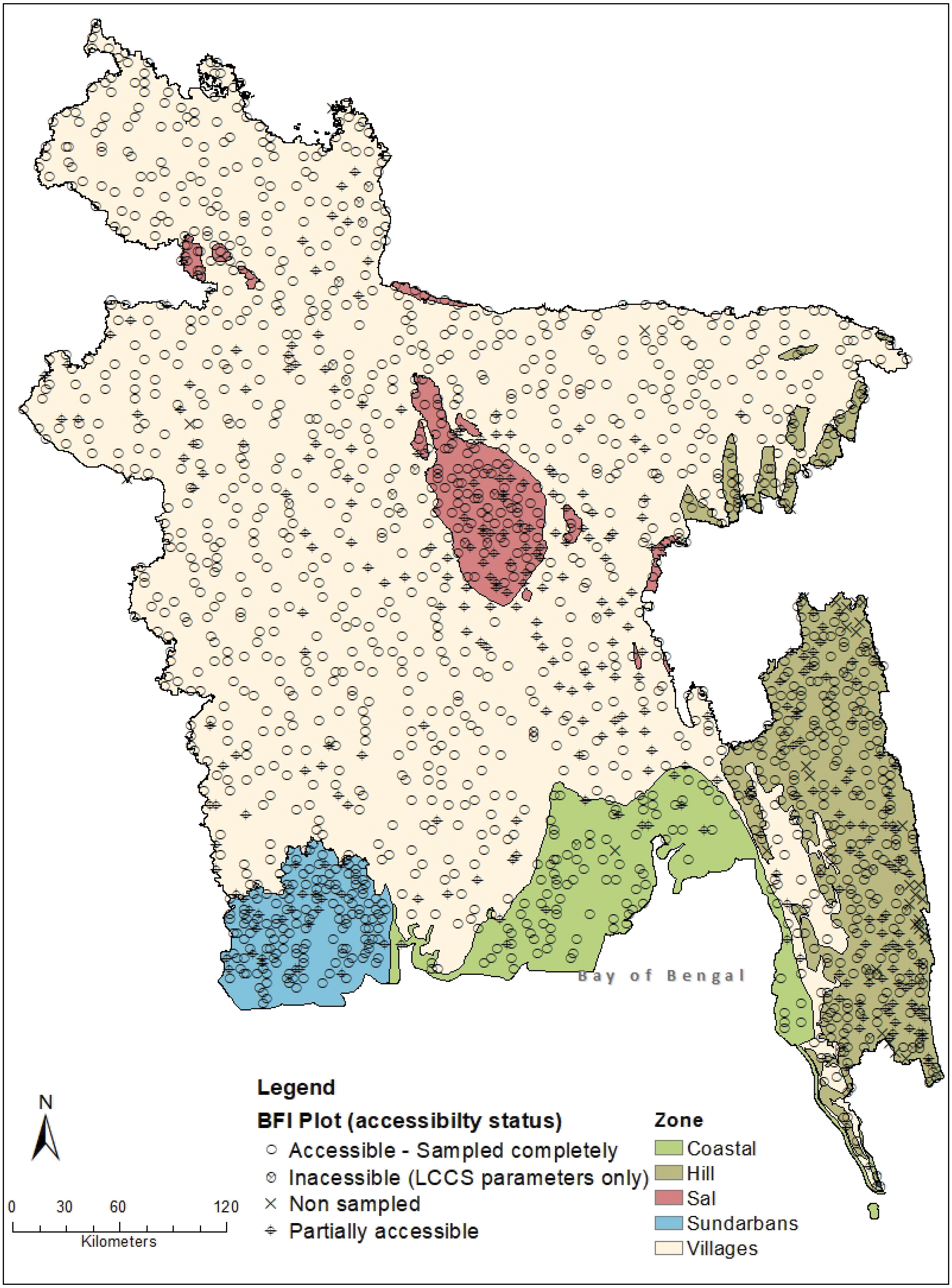


Figure 2.12: The distribution of BFI plots according to plot status.

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.

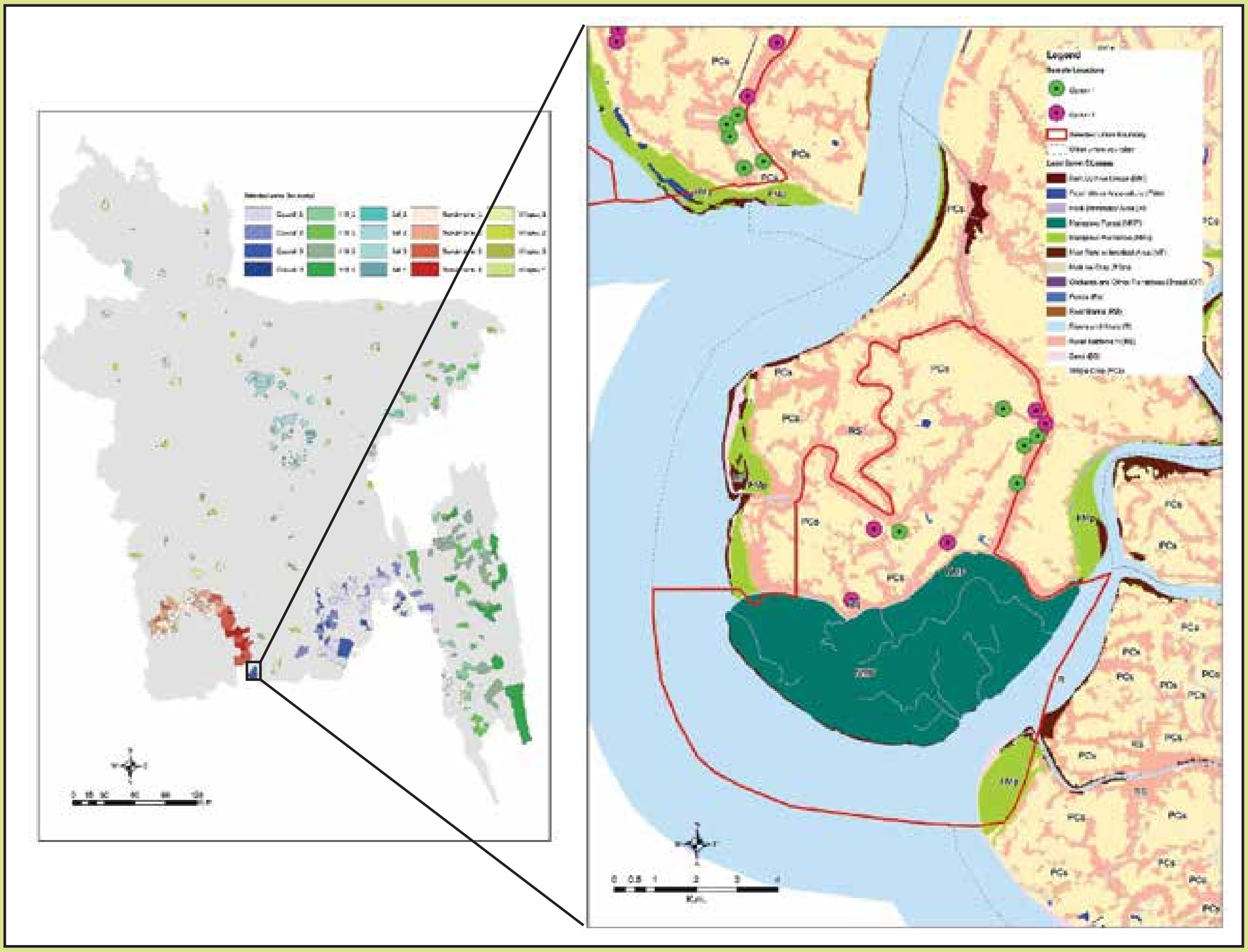


Figure 2.13: Left: Map of 320 unions selected for socio-economic field data collection stratified by 20 HTAC's. Right: Map of a single union indicating 10 GPS points where field teams chose to visit either even or odd numbers, but not both.

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 Chattogram 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

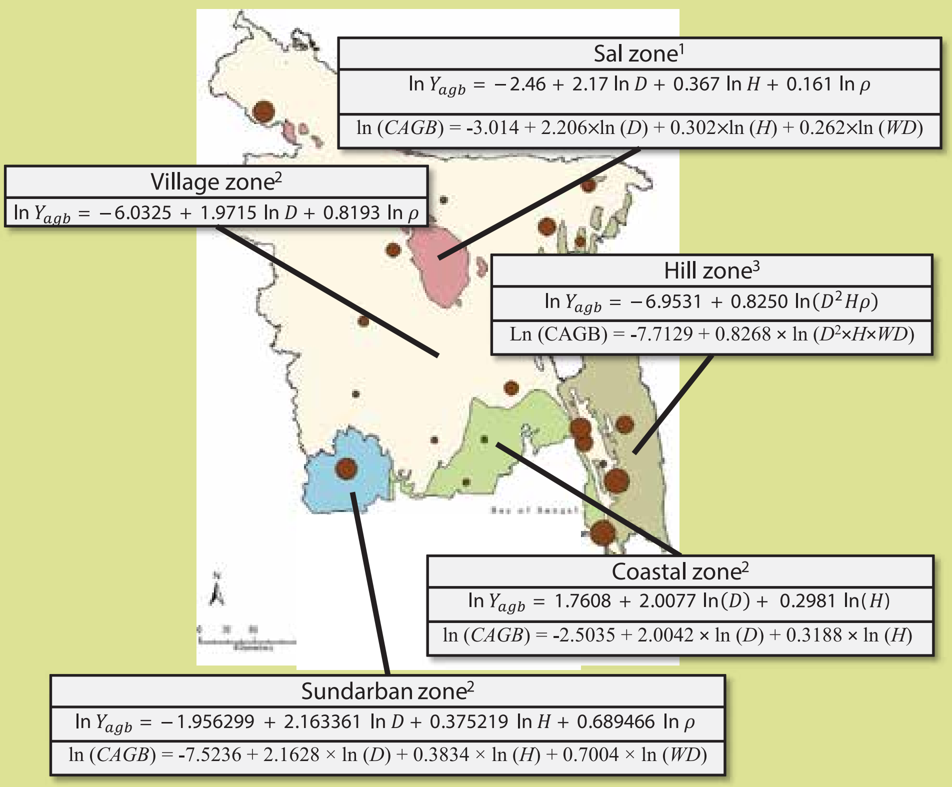


Figure 2.14: Spatial distribution of 517 species specific and nine zone specific allometric equations considered for volume, carbon, and biomass estimations. Larger circles represent more species specific equations from locations throughout Bangladesh. Boxed equations refer to zone specific equations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

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 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.

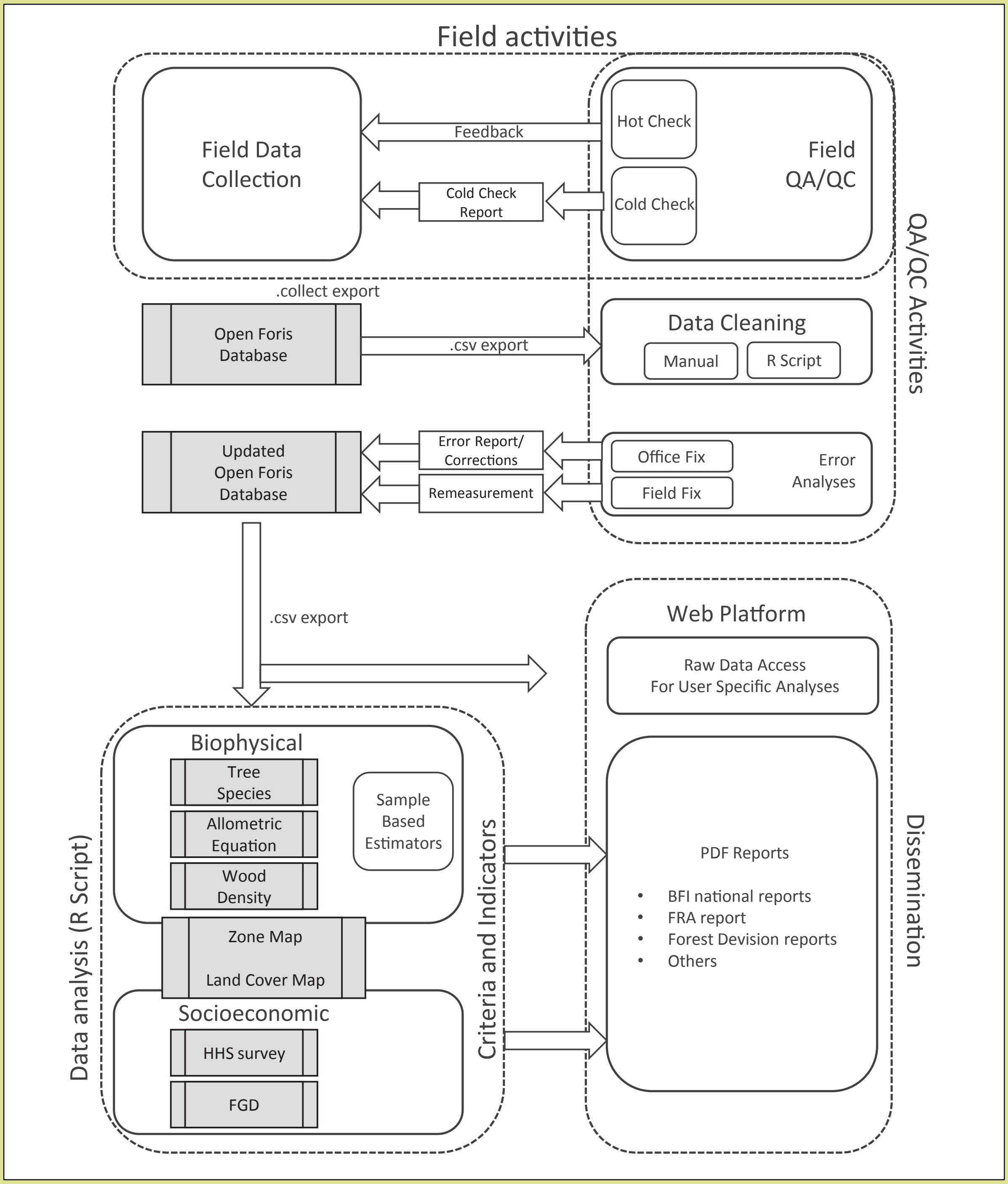


Figure 2.15: Flow diagram of the data management, data cleaning, QA/QC and estimation processes used in the biophysical and socio-economic surveys.

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.

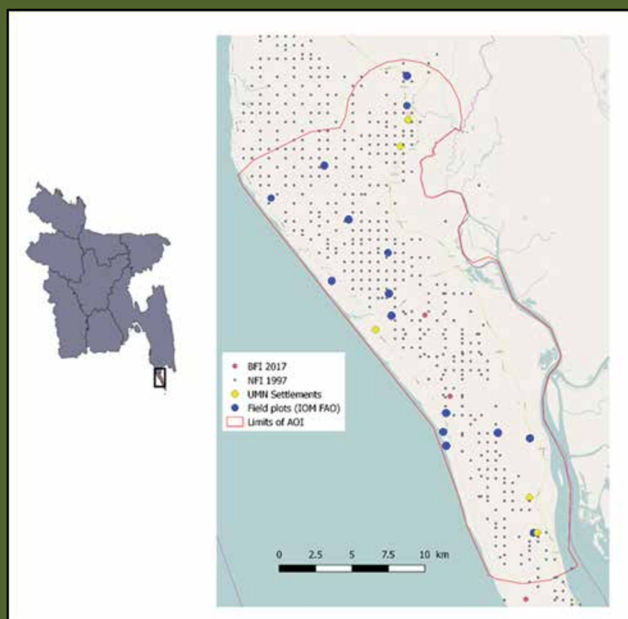


Figure 2.16: The locations of 14 additional field plots that were integrated with existing BFI plots in Cox's Bazar district.

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.

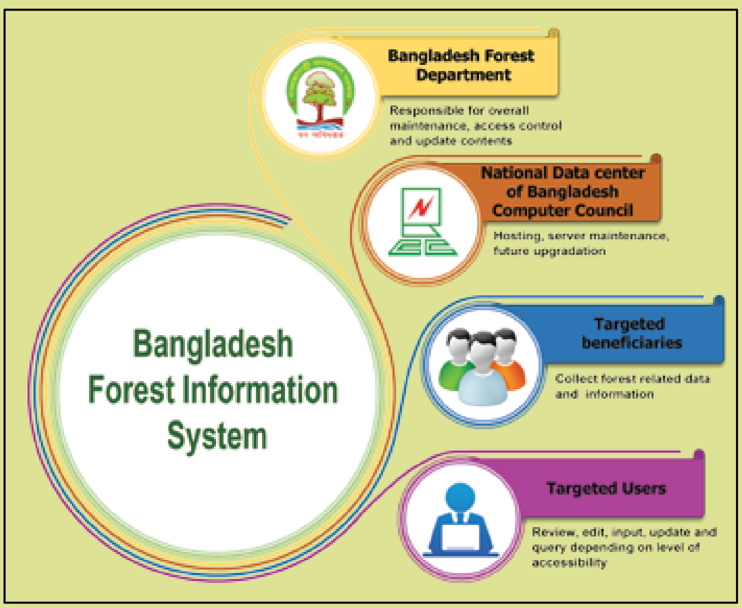
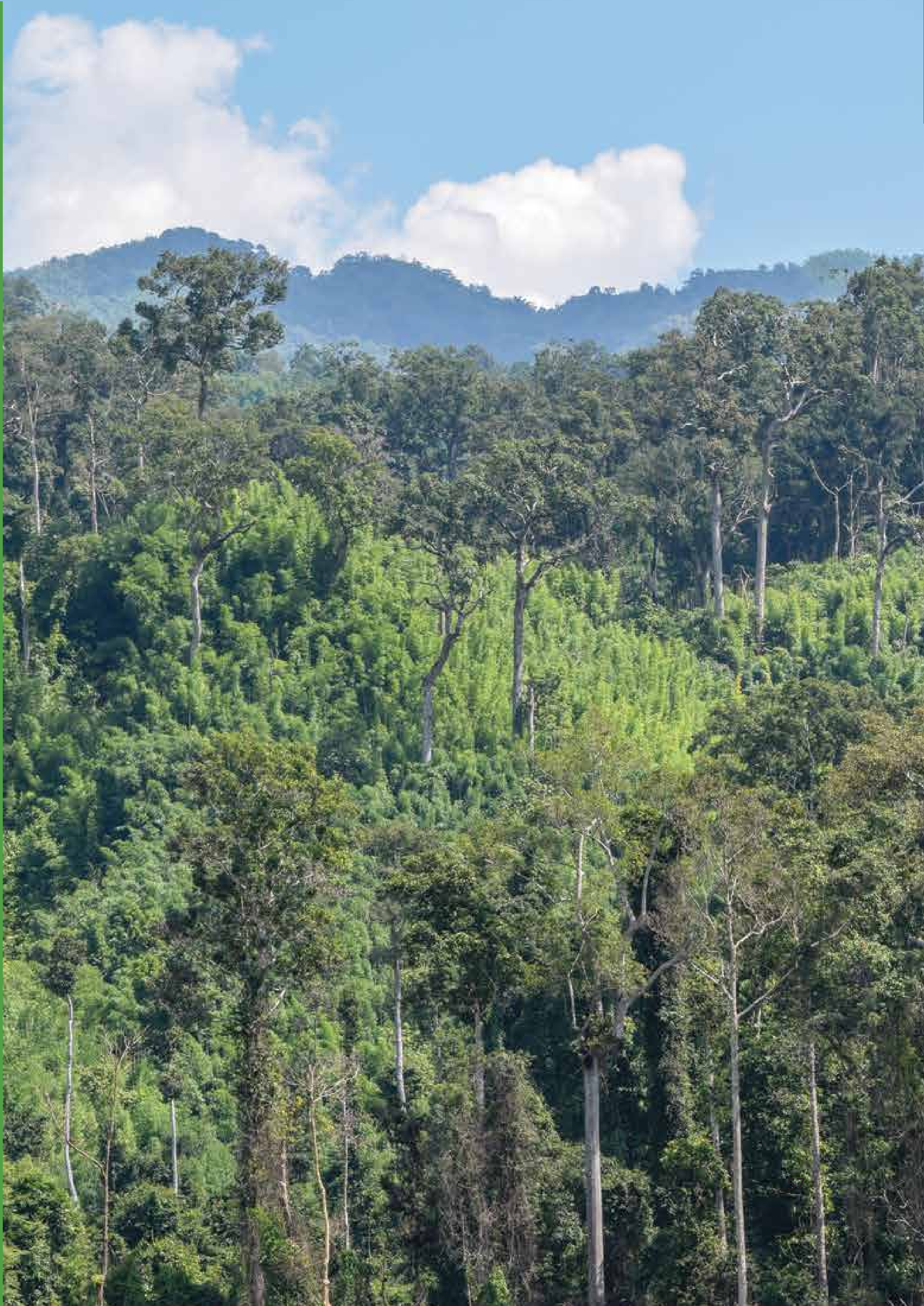


Figure 2.17: The purposes and users of the Bangladesh Forest Information System.

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

Section 3:

Criteria 1 - Forest Extent and Tree Cover Changes



Tree diversity in hill forest, Bandarban *©Rajib Mahmud*

Section 3

Criteria 1

Tree and Forests Extent

Section Highlights

- Remote sensing information was used to report the forest and tree extent.
- In 2015, forest cover in Bangladesh was 1,884,019 ha, or 12.8% of the total country area. This amounts to about 11.7 ha forest cover per 1000 people.
- Hill Forest is the largest forest type by area (4.6% of the country area) followed by Shrubs with scattered trees (4.2%) and Mangrove Forest (i.e. Sundarban) (2.7%).
- All classes defined as Other Land (i.e. TOF) combined to cover a total of 87.2% of the country, and Permanent Crop and Rural Settlement alone combined to cover 69.8% of the area.
- The highest increase of average tree cover occurs within Mangrove Plantation (12%), while the highest decrease occurs in Plain Land Forest (Sal Forest) (18%).

Introduction

This criterion describes the areas and distribution of land cover and tree cover and tree cover changes over time. Land cover is not only the area, but also the attributes of the area. The extent and spatial distribution of forest cover as a specific type of land cover is used to understand the status of resources and their changes. Forest cover is the aggregation of different forest and plantation land cover types. Tree cover is different from forest cover because trees can occur within any land cover class. Tree cover change is used to understand at a fine resolution changes in TOF, in addition to forest extent changes. Questions that drive this criterion include – in what areas are changes in tree cover concentrated the most in the country? Land cover is also the link between biophysical and socio-economic components of the BFI. Future BFI cycles will monitor the trends of forest and tree cover indicators over time.

Methods

Multi-spectral ortho (Level 3) SPOT6/7 images of 6-meter spatial resolution with maximum 10% cloud coverage were used for the development of land cover map 2015. The legend classes were derived from the Land Representation System of Bangladesh (LRSB) of Bangladesh based on the distinction of classes from satellite image interpretation, availability of ancillary data, and expert knowledge. Multi resolution segmentation algorithm was used to develop image objects using the bands green, red and near-infrared (NIR) with equal weights as input layers. The image objects developed were then used as the basic unit of classification and land cover code was assigned to each segment by trained photo interpreters. Based on the LRSB class hierarchy, the legend classes of the land cover map 2015 are aggregated for assessing extent of forest, other wooded land, etc. Note that while some land cover classes are named for a single condition or vegetation type (e.g. Bamboo Forest, Single Crop, and Pond) tree species may still occur within the class.

The 2015 Land Cover Map has 33 land cover classes which can be grouped into Forest or Other Land following FRA definitions (FAO 2018b). The following land cover classes were considered as Forest cover: Bamboo Forest, Forest Plantation, Hill Forest, Mangrove Forest, Mangrove Plantation, Plain Land Forest (Sal Forest), Rubber Plantation, Shrubs with scattered trees, Swamp Forest. The Other Land category is used synonymously with the term TOF in this report and is comprised of classes such as Rural Settlement, Single and Multiple crop, and Rivers and Khals. A table of all land cover class assignments to Forest or Other Land is given in the Appendix 2.1. (Note that Forest cover is different from Forest Land, which is all the land managed by the FD, regardless of whether forest is present or not).

Wall-to-wall Landsat based tree cover extent and change maps, developed by RIMS unit of FD and the University of Maryland (Potapov, Siddiqui *et al.* 2017), have been integrated with land cover 2015 data. At the scale of the polygons of the land cover map 2015 zonal statistics of the 2000-2014 tree cover data are computed. This results in each polygon of the land cover map containing the number of pixels with tree cover in 2000, the number of pixels with tree cover gains and the number of pixels with tree cover loss for each year between 2000 and 2014. Based on this, tree cover percentage within each land cover was calculated for 2000 and 2015 (assuming 2014 tree cover), and changes in percentage tree cover were computed.

3.1

Extent of Forest and Tree Resources

Description

Of the 33 classes in the land cover map, 10 classes (i.e. Bamboo Forest, Forest Plantation, Hill Forest, Mangrove Forest, Mangrove Plantation, Plain Land Sal Forest, Rubber Plantation, Shrubs with scattered tree, Swamp Forest and Swamp Plantation) belong to Forest (according to FRA definition) which cover about 1,884,019 ha of land (12.8% of the country). Forest cover is highest in the Hill and Sundarban zones and lowest in the Village, Coastal, and Sal zones (Table 3.1).

Permanent Crop (Single plus Multiple Crop) is the largest land cover class, accounting for 48.6% of the total country area. Rural Settlement is the next largest class covering 21.2% of the area. All the classes defined as Other Land combined to cover a total of 87.2% of the country (Figure 3.1; Table 3.2).

Highlights

- Hill Forest is the largest forest type within the Forest classes (36.3% of Forest area) followed by Shrubs with scattered trees and Mangrove Forest (Sundarbans) (32.6% and 21.4% of forest, respectively) while swamp forest represented only 0.013%.
- Within the BFI zones, forest coverage is highest in the Hill (about 78.0% of the zone), followed by Sundarban (about 63.2% of the zone).
- The Sundarban zone is almost exclusively covered by either Mangrove Forest (63.2%) or Rivers and Khals (36.8%).
- Orchards (tree or shrub) and plantations were only 1.7% and 1.1% of the total area, respectively.

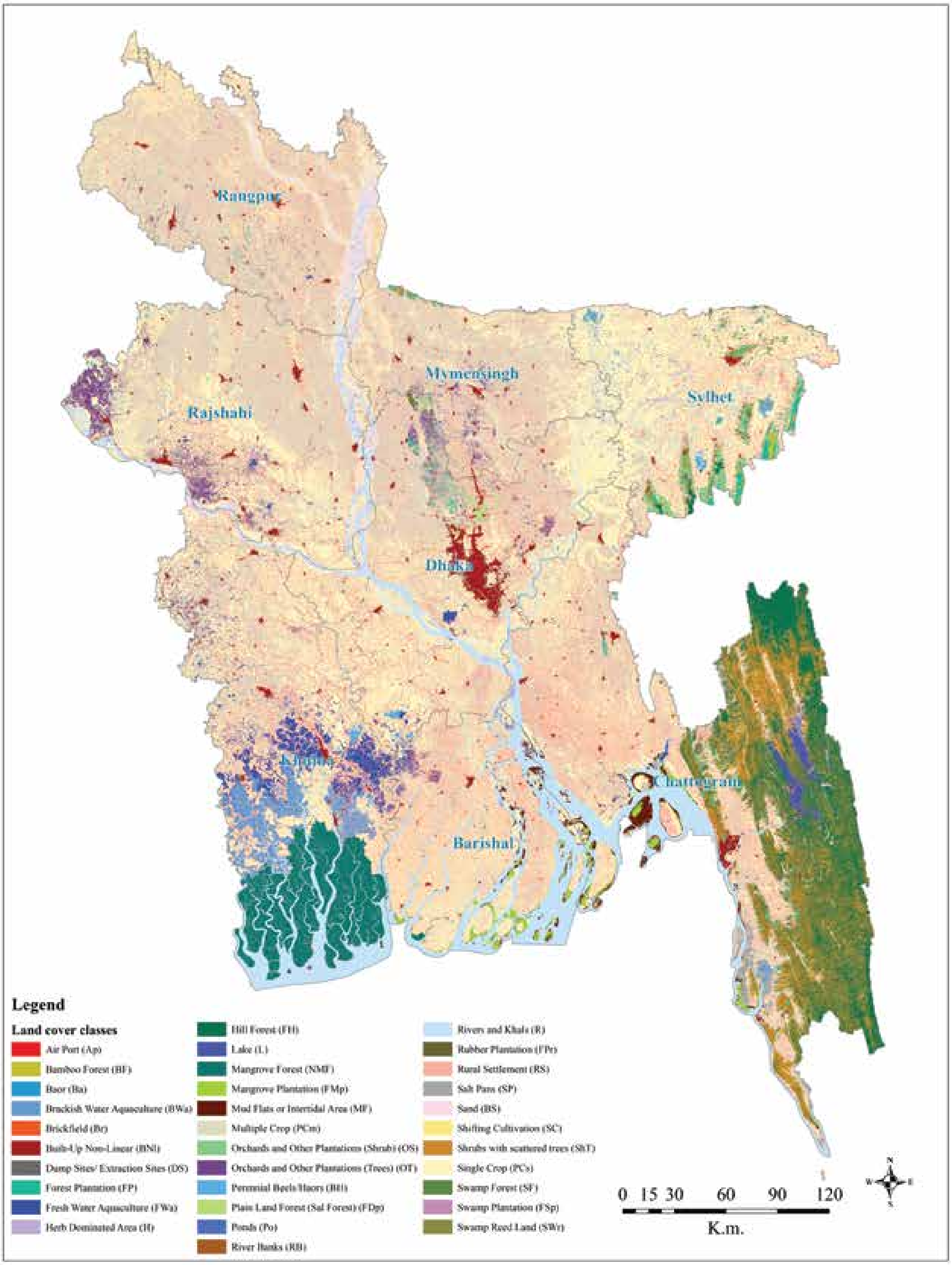


Figure 3.1: The Land Cover Map of Bangladesh 2015

Table 3.1: Distribution of Forest cover and Other Land (TOF) cover within zones.

Zone	FRA land cover[1]	Area (% of total zone area)	Area (ha)
Coastal	Forest	6.2	61,497
	Other Land (TOF)	93.8	925,121
Hill	Forest	78.0	1,338,807
	Other Land (TOF)	22.0	377,342
Sal	Forest	8.7	46,338
	Other Land (TOF)	91.3	488,092
Sundarban	Forest	63.2	399,900
	Other Land (TOF)	36.8	232,779
Village	Forest	0.3	37,476
	Other Land (TOF)	99.7	10,849,647
National	Forest	12.8	1,884,019
	Other Land (TOF)	87.2	12,872,981

[1] Other Land is used to define Trees Outside Forest (TOF) throughout the report.

Table 3.2: Disaggregated levels and areas of each land cover class.

Land cover class							Land cover area	
Level1	Level2	Level3	Level4	Level5	Level6	FRA[1]	ha	% of total
Vegetated Are	Terresterial	Natural	Tree Dominated Area	Evergreen Forest	Hill Forest	F	683,852	4.63
				Mixed Forest	Bamboo Forest	F	5,686	0.04
				Deciduous Forest	Plain Land Forest (Sal Forest)	F	18,918	0.13
			Shrub Dominated Area	Shrub Dominated Area	Shrubs with scattered trees	F	614,537	4.16
			Herb Dominated Area	Herb Dominated Area	Herb Dominated Area	OL	65,424	0.44
		Cultivated	Cultivated Trees	Rubber Platation	Rubber Plantation	F	23,684	0.16
				Forest Plantation	Forest Plantation	F	79,299	0.54
				Orchards and Other Plantation	Orchards and Other Plantations (Trees)	OL	180,698	1.22
			Cultivated Shrub	Orchards and Other Plantation	Orchards and Other Plantations (Shrub)	OL	70,279	0.48
			Herbaceous Crops	Permanent crop	Single Crop	OL	4,348,516	29.47
					Multiple Crop	OL	2,822,319	19.13
				Shifting Cultivation	Shifting Cultivation	OL	34,253	0.23
	Aquatic or Regularly Flooded	Natural	Tree Dominated Area	Swamp Forest	Swamp Forest	F	140	0.00
				Mangrove Forest	Mangrove Forest	F	402,185	2.73
			Shrub Dominated Area	Swamp Reed Land	Swamp Reed Land	OL	13,437	0.09
		Cultivated	Tree Crop	Mangrove Plantation	Mangrove Plantation	F	55,089	0.37
				Swamp Plantation	Swamp Plantation	F	628	0.00
Rural Settlement	Rural Settlement	Rural Settlement	Rural Settlement	Rural Settlement	Rural Settlement	OL	3,124,468	21.17
Non-Vegetated Area	Terresterial	Natural	Soil, Sand Deposit	Mud Flats or Intertidal Area	Mud Flats or Intertidal Area	OL	76,301	0.52
				Sand	Sand	OL	151,267	1.03
				River Banks	River Banks	OL	782	0.01
		Artificial	Built-up Non-Linear	Built-up Non-Linear	Built-up Non-Linear	OL	179,223	1.21
			Airport	Airport	Airport	OL	2,538	0.02
			Dump / Extraction Sites	Dump / Extraction Sites	Dump / Extraction Sites	OL	4,399	0.03
			Brickfield	Brickfield	Brickfield	OL	20,966	0.14
			Salt Pans	Salt Pans	Salt Pans	OL	37,272	0.25
	Water	Natural	Rivers and Khals	Rivers and Khals	Rivers and Khals	OL	1,253,573	8.49
			Standing Natural Waterbody	Baor	Baor	OL	18,457	0.13
				Perennial Beels/Haors	Perennial Beels/Haors	OL	57,639	0.39
		Artificial	Standing Large Artificial Waterbody	Lake	Lake	OL	53,318	0.36
			Standing Small Artificial Waterbody	Fresh Water Aquaculture	Fresh Water Aquaculture	OL	190,330	1.29
				Brackish Water Aquaculture	Brackish Water Aquaculture	OL	156,962	1
				Ponds	Ponds	OL	10,561	0.07
						Total F	**1,884,019**	**12.8**
						Total OL	**12,872,981**	**87.2**
						Total	**14,757,000**	**100**

[1] F - Forest, OL - Other Land according to FRA (2018). OL is synonymous with Trees Outside Forest (TOF) in this report.

3.2

Tree Cover Changes

Description

For specific land cover classes, the average tree cover increased in Mangrove Plantation, Mangrove Forest, and Rubber Plantation. On the other hand, tree cover within Plain Land Sal Forest, Shifting Cultivation, Hill Forest, Forest Plantation, Shrub with Scattered Trees, Bamboo Forest, and others decreased from 2000 to 2015 (Figure 3.2).

Highlights

- The highest increase of tree cover occurrs within Mangrove Plantation (12%) and Mangrove Forest (4%).

- The highest decrease of tree cover occurrs within Plain Land Forest (Sal Forest) (18%).

- A decrease in average tree cover is also observed in Hill Forest (8%), Forest Plantation (7%) and Bamboo Forest (5%).

The great white egret, Sundarban *©Falgoonee Kumar Mondal*

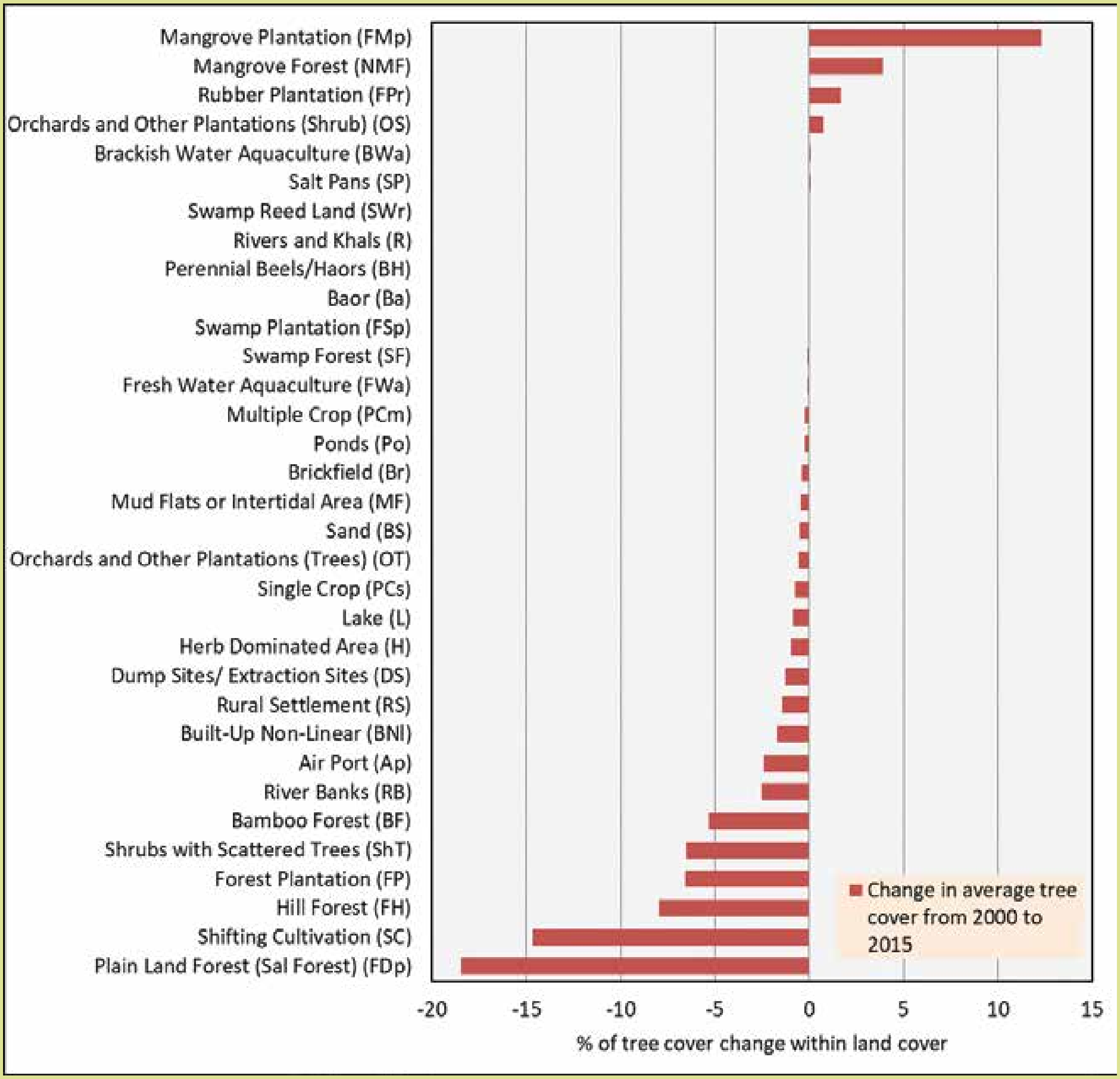


Figure 3.2: The change in tree cover within 2015 land cover classes.

Field team movement ©*Matieu Henry*

Section 4:

Criteria 2 - Biological Diversity and Conservation

Rubber plantation, Tangail ©*Falgoonee Kumar Mondal*

Section 4

Criteria 2

Biological Diversity and Conservation

Section Highlights

- A total of 390 tree species are identified in the biophysical inventory. TOF areas have more species than Forest areas (286 and 274, respectively).
- *Heritiera fomes* 10,094 seedlings/ha in the Sundarban zone) and *Shorea robusta* (4065 seedlings/ha in the Sal zone) have the highest seedling zone level densities.
- There are 11 IUCN Red List tree species inventoried in the BFI, including *Dipterocarpus spp.* (Garjan) and *Corypha taliera* (Tali) which are considered critically endangered in Bangladesh.
- The Mangrove Forest holds 44% of the national seedling stock, mainly comprised of *Heritiera fomes* (Sundri), *Ceriops decandra* (Goran), and *Excoecaria agallocha* (Gewa).

Introduction

Forests are habitats for both plant and animal species. This criterion describes the structure and composition of trees and forests, and the abundance of regenerating and threatened tree species. Monitoring these characteristics over time informs conservation initiatives and policies. This criteria answers questions such as *"what is the status of introduced and regenerating species?"*, and *"where do endangered species occur?"* In Bangladesh, there is a large variation observed in the structure and composition of tree species. This ranges from the Rural Settlements where species richness is highest with moderate tree densities to the Mangrove Forest which is relatively homogeneous in terms of species but has very high tree densities.

Methods

Trees and saplings were surveyed in small, medium and large nested subplots (Section 2.3.3). Seedlings were counted in the small subplots. References to "trees" in basal area and recruitment estimations include both saplings and trees. The Bangladesh National Herbarium Tree Species Database was used for tree species identification. Where summary statistics are by species, only the ten most dominant species are shown whereas the complete list can be found in the Appendix 4 tables. Zone level estimations of basal area, stem density, and other statistics followed estimators prescribed for stratified random sampling as in Scott (2018). For estimates by land cover class, the classes were assigned to the land feature of the biophysical inventory plot post hoc by overlaying the 2015 Land Cover Map onto the subplot perimeters and extracting the areas. The R code for the estimations can be found in the BFIS e-Library (see also Hossain, Anik *et al.* 2019). Note that all data were collected from the biophysical inventory, except in the case of Sections 4.6 to 4.7 which show data from the socio-economic survey. Cells were left blank where there was no sample of that condition and a 0 value indicates < 0.01 of the respective unit. More estimates of stem densities, DBH, height, recruitment and basal area at the family level and for all species are found in the Appendix 4 tables.

Maps were produced by applying the mean estimate by land cover class and zone to the polygons of the 2015 Land Cover Map. When there was no or little data for very small land cover areas, values were substituted from other classes. For example, as there was no plots occurring in Herb Dominated Area in the Coastal or Sal zones to estimate growing stock value, the value for Herb Dominated Area in the Village zone was substituted.

Goalpata (Nypa) transportation, The Sundarban *©Falgoonee Kumar Mondal*

4.1

Tree Species Composition, Stem Density and Size Characteristics

4.1.1 Plant Diversity and Basal Area

Description

A total of 392 tree species were identified in the biophysical survey of the BFI. The number of species is highest in the Hill zone (primarily Hill Forest) followed by the Village zone (primarily Rural Settlement). The number of tree species in TOF is actually somewhat higher than in Forest (Table 4.1 and 4.2). The Hill Forest is naturally regenerated forest whereas trees in Rural Settlement are mostly planted, especially fruit trees. Although the Rural Settlement has 26% of the total number of stems, it has 49% of the total basal area, perhaps reflecting the preference for specific tree species and larger trees for their services by those who plant them.

Basal area includes both saplings and trees. The Mangrove Forest is also naturally regenerated and has the highest stem density and basal area (m^2/ha) though its tree species richness is much less than other land cover classes. Trees in agricultural land primarily used for cultivation (Multiple and Single Crop) have low sapling and tree densities (49 to 56 stem/ha) and low basal area (0.80 to 0.91 m^2/ha). A complete list of tree species and their basal areas is found in the Appendix 4.1 (a, b, c).

Highlights

- Hill zone harbors 284 tree species which is the highest among the zones.
- The national average basal area density is 4.52 m^2/ha and the national total is 60.84 million m^2.
- Basa area density in Forest is 3.4 times higher than in TOF.
- Multiple and Single Crop has very low stem density yet high number of species which may reflect agro-forestry practices.

Table 4.1: Number of tree species, tree and sapling stem densities and tree and sapling basal area by zone.

Zone	Number of species[1]	Tree stem density (stem/ha)	Total number of stem (million)	Basal area (m^2/ha)	Total basal area (million m^2)
Coastal	103	229	969	8.82	4.50
Hill	284	146	630	6.23	10.34
Sal	113	169	268	5.89	3.08
Sundarban[2]	28	661	6,861	22.29	8.99
Village	232	98	184	3.28	33.93
National	392	129	472	4.52	60.84

[1]Excludes unknown tree species

[2]Sundarban zone has only two land cover classes - Mangrove forest and River Bank. Tree and sapling density for the whole Sundarbans was 6861 where for Mangrove forest class the density was 6843 stem/ha and for River Bank 23418 stem/ha. River Bank tree and sapling density was 470 stem/ha for all zones.

Table 4.2: Number of tree species identified, tree and saping stem densities and basal area by land cover class, ranked by basal area (m^2/ha).

Land Cover Classes	Number of species	Tree stem density (stem/ha)	Sapling and tree density (stem/ha)	Total number of stems (million)	Basal area (m^2/ha)	Total Basal area (million m^2)
Forest						
Mangrove Forest	28	662	6843	2,758	22.26	8.97
Mangrove Plantation	12	325	2156	355	15.8	2.61
Plain Land Forest (Sal Forest)	18	539	810	34	14.61	0.62
Rubber Plantation	8	249	507	25	9.82	0.49
Hill Forest	229	210	788	488	9.38	5.80
Forest Plantation	88	256	759	71	8.85	0.83
Shrubs with scattered trees	158	103	696	398	4.27	2.44
Bamboo Forest	2	10	112	1	0.84	0.004
Total Forest	**274**	**292**	**2192**	**4,130**	**11.55**	**21.764**

Land Cover Classes	Number of species	Tree stem density[1] (stem/ha)	Sapling and tree density[1] (stem/ha)	Total number of stems (million)	Basal area (m^2/ha)	Total Basal area (million m^2)
Other Land (TOF)						
Rural Settlement	249	315	578	1671	10.18	29.45
Orchards and Other Plantations (Trees)	65	192	308	61	9.61	1.90
Swamp Reed Land	2	92	92	1	5.29	0.05
Built-Up Non-Linear	33	128	231	19	4.77	0.40
Orchards and Other Plantations (Shrub)	35	104	146	14	4.63	0.45
Shifting Cultivation	29	46	1201	37	3.44	0.11
River Banks	24	41	470	11	2.73	0.06
Ponds	7	71	71	1	2.71	0.022
Multiple Crop	90	26	56	177	0.91	2.89
Single Crop	122	22	49	224	0.80	3.65
Fresh Water Aquaculture	13	15	15	2	0.45	0.05
Brickfield	3	3	3	0	0.42	0.01
Herb Dominated Area	4	15	15	1	0.37	0.02
Sand	2	0.3	0.3	0	0.03	0.004
Brackish Water Aquaculture	1		31	1	0.01	0.0005
Total Other Land (TOF)	**286**	**101**	**192**	**2,220**	**3.38**	**39.07**

[1]Trees are stems with diameter ≥ 10cm; saplings are stems with diameters between 2 to 10cm.

4.1.2 Stand Characteristics by Species

Description

Diameters and heights vary widely across zones indicating the growth forms of the dominant trees that occur in those zones. There were several individual trees inventoried with DBH greater than 150 cm, namely, *Bombax ceiba* (190 cm), *Ficus benghalensis* (182 cm), *Duabanga grandiflora* (175 cm), *Avicennia officinalis* (164 cm) etc. There were two individual trees that were greater than 45 m in height, both of them in the Hill zone - *Swintonia floribunda* (45.3 m), and *Dipterocarpus costatus* (45.3 m).

The lower height and DBH classes have more stem density than higher size classes (Figure 4.1 and 4.2). More specifically, height classes greater than 20m in all zones have the least density (<1 stem/ha) indicating lower tree populations in the higher size classes. The stem density of Sundarban is about 3.5 times higher than the total stem density of the remaining four zones when trees had DBH's of 2 to 10 cm.

C. decandra, E. agallocha, and H. fomes are the three highest species in terms of stem density across the country, though they almost exclusively occur in the Sundarban zone (Appendix 4.1.2). *T. grandis* dominated the Hill zone and *E. agallocha* is highest in the Coastal zone (Table 4.3). *S. mahagoni* has the highest density in the Village zone, while *S. robusta* is highest in the Sal zone. Stem density, DBH and height estimates at the family level and for all species can be found in the Appendix 4.1.2 (a,b,c).

Highlights

- Stem density is highest in DBH classes <10 cm and height class <5 m.
- The three highest densities by species are all found in the Sundarban zone (*C. decandra*, *E. agallocha*, and *H. fomes*).
- Aam (mango) is the largest growing of the most common species, reaching diameters of 126 cm and heights of 37m (Table 4.3).

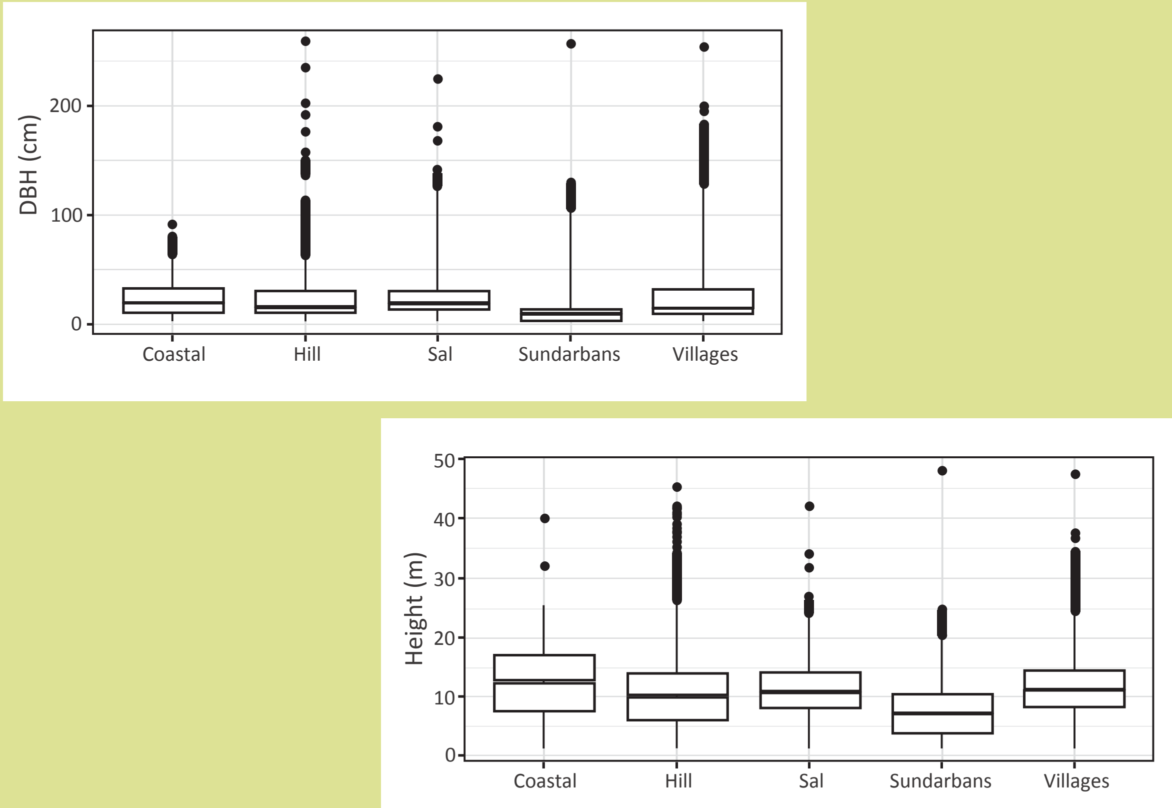


Figure 4.1: Ranges and medians of diameters (top) and heights (bottom) for all tree individuals by zone.

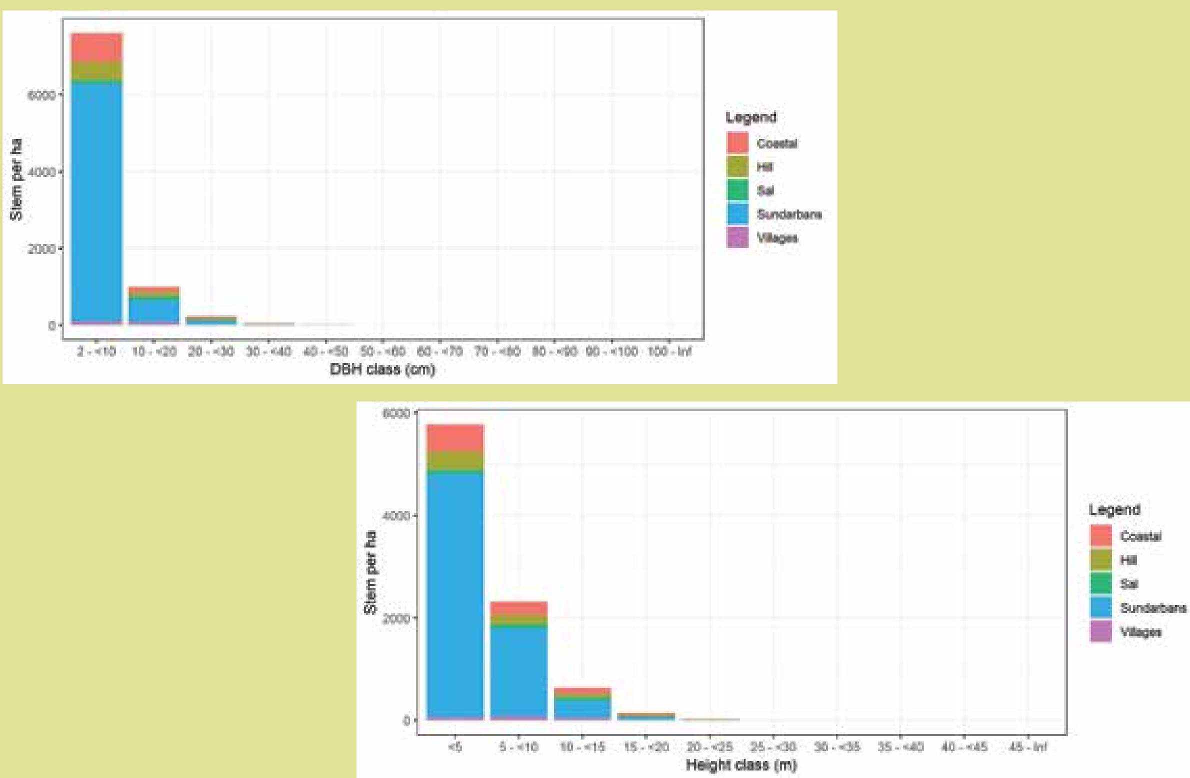


Figure 4.2: The distribution of stem density for each diameter class (top) and height class (bottom) by zone.

Table 4.3: Stem densities, Diameter at Breast Height (DBH), and height statistics of the ten most dominant tree species of Bangladesh.

Tree Scientific Name	Local Name	Tree stem density[1] (stem/ha)	Tree and sapling stem density[1] (stem/ha)	DBH (cm)			Height (m)		
				Min	Mean	Max	Min	Mean	Max
Coastal Zone									
Excoecaria agallocha	Gewa	10	523	2	9.6	46.7	1.5	7.0	22.4
Sonneratia apetala	Keora	86	104	2	78.7	130	1.8	16.8	24.8
Areca catechu	Supari	59	100	3	11.8	69.6	1.7	11.3	22.1
Memecylon edule	Anjan		35	2	3.5	7.8	2.1	3.7	7.21
Samanea saman	Siris	14	24	2	35.7	110.8	1.7	14.8	37.5
Hill Zone									
Tectona grandis	Shegun	34	117	1.8	15.2	48	1.4	10.1	29.6
Macaranga denticulata	Bura/Khoi	6	48	2	8.8	31.6	1.6	6.4	14.7
Acacia auriculiformis	Akashmoni	7	39	2	15.2	61.4	1.6	11.6	32.5
Ficus carica	Anjir/Dumur	4	37	2	11.2	78.5	1.7	6.2	27.9
Gmelina arborea	Gamari	7	18	2.05	25.9	117.1	2.1	12.6	31.6
Sal Zone									
Shorea robusta	Sal	43	76	2	19.1	64.5	1.8	11.7	26
Acacia auriculiformis	Akashmoni	43	65	2	15.2	61.4	1.6	11.6	32.5
Artocarpus heterophyllus	Kathal	16	17	2	26.6	78.2	2.1	9.9	33.2
Swietenia mahagoni	Mehogoni	8	16	2	18.9	86.1	1.4	11.4	32
Mangifera indica	Aam	8	11	2	27.8	125.7	1.5	10.0	36.5
Sundarban Zone									
Ceriops decandra	Goran	0	2,522	2	2.8	9.8	1.4	3.1	11.2
Excoecaria agallocha	Gewa	288	2,111	2	9.6	46.7	1.5	7.0	22.4
Heritiera fomes	Sundri	331	1,744	2	13.0	117	1.4	9.5	24.8
Aglaia cucullata	Amoor	3	230	2	4.9	65	1.46	4.2	17.8
Cynometra ramiflora	Singra	1	65	2	5.9	41.5	2.5	4.5	16

Tree Scientific Name	Local Name	Tree stem density (stem/ha)	Tree and sapling stem density (stem/ha)	DBH (cm)			Height (m)		
				Min	Mean	Max	Min	Mean	Max
Village Zone									
Swietenia mahagoni	Mehogoni	13	31	2	18.9	86.1	1.4	11.4	32
Areca catechu	Supari	23	30	3	11.8	69.6	1.7	11.3	22.1
Mangifera indica	Aam	10	18	2	27.8	125.7	1.5	10.0	36.5
Eucalyptus camaldulensis	Eucalyptus	5	11	2	18.0	55.5	1.5	14.2	34.5
Acacia auriculiformis	Akashmoni	3	10	2	15.2	61.4	1.6	11.6	32.5
National Level									
Excoecaria agallocha	Gewa	9	83	2	9.6	46.7	1.5	7.0	22.4
Ceriops decandra	Goran		76	2	2.8	9.8	1.4	3.1	11.2
Heritiera fomes	Sundri	10	53	2	13.0	117	1.4	9.5	24.8
Areca catechu	Supari	20	27	3	11.8	69.6	1.7	11.3	22.1
Swietenia mahagoni	Mehogoni	11	26	2	18.9	86.1	1.4	11.4	32

[1]Trees are stems with diameter ≥ 10cm; saplings are stems with diameters from 2 to 10cm.

4.2

Regeneration and Recruitment

4.2.1 Regeneration by Species and Zone

Description

Seedling density varies widely by zone. Similar to tree densities (Section 4.1.2), mangrove species have some of the highest seedling densities (*H. fomes, C. decandra and E. agallocha*) (Table 4.4). *S. robusta* seedlings dominated the Sal zone. Common seedlings in the Village zone included *F. carica, S. cumini, C. mitis,* and *S. asper*. The most common seedling specie of the Hill zone is *F. carica*. Seedling density estimates for all species can be found in the Appendix 4.2.1 (a,b).

Highlights

- Seedling density is highest in mangrove species of the Sundarban zone. For example, *H. fomes* is 5.9 times higher than the national average (see Section 4.2.2)
- *S. cuminiand E. agallocha* seedlings each occur as a top five species in more than one zone.
- The most evenly distributed seedling species occurs in the Village zone.
- The top three species in the country in terms of seedling density are *H. fomes, C. decandra*, and *S. robusta*.

Bashpata (Podocarpus Neriifolius) ©Falgoonee Kumar Mondal

Table 4.4: Five most dominant seedling specie per zones.

Seedling Scientific Name	Local name	Seedling density (seedling/ha)
Coastal Zone		
Excoecaria agallocha	Gewa	991
Memecylon edule	Anjan	294
Sonneratia apetala	Keora	98
Ceriops decandra	Goran	94
Ficus hispida	Dumur	61
Hill Zone		
Ficus carica	Anjir/Dumur	146
Tectona grandis	Shegun	145
Macaranga denticulata	Bura/Khoi	87
Corypha taliera	Tali	76
Grewia nervosa	Asar	67
Sal Zone		
Shorea robusta	Sal	4,065
Acacia mangium	Mangium	355
Acacia auriculiformis	Akashmoni	272
Syzygium cumini	Kala-Jaam	61
Leucaena leucocephala	Ipil-ipil	49
Sundarban Zone		
Heritiera fomes	Sundri	10,094
Ceriops decandra	Goran	6,923
Excoecaria agallocha	Gewa	1,225
Aglaia cucullata	Amoor	815
Phoenix sp.	Hental	524
Village Zone		
Ficus carica	Anjir/ Dumur	49
Caryota mitis	Chau gola/ Burmese pa	35
Syzygium cumini	Kala-Jaam lm	34
Streblus asper	Sheora	29
Diospyros blancoi	Beelati Gab	25
National Level		
Heritiera fomes	Sundri	303
Ceriops decandra	Goran	211
Shorea robusta	Sal	161
Excoecaria agallocha	Gewa	74
Ficus carica	Anjir/Dumur	56

4.2.2 Regeneration

Description

Seedling density is by far the highest in the Sundarban zone, more than 12 times higher than the national average, which also resulted in this zone containg 44% of the total number of seedlings in the country (Table 4.5). Nevertheless, the diversity of seedlings among zones is the highest in the Hill zone. In contrast, the Sundarban zone has the lowest number of species and families yet the highest number of total seedlings.

Seedlings occur in 19 of the 33 land cover classes and the highest totals are in the Mangrove Forest, Rural Settlement, and Hill Forest (Table 4.6). For number of species, unlike the case of tree and saplings, the number of seedling species observed is much higher in Forest areas (216) compared to TOF (160).

Highlights

- There are about 19.1 billion estimated seedlings.
- There are 135 regenerating species within the Hill Forest.
- Seedling density in Forest area is 15 times higher than in TOF.
- Seedling density in the Mangrove Forest is 4.3 times higher than in Mangrove Plantation.

Table 4.5: Seedling number, species and family composition by zones.

Zone	Number of species[1]	Number of families[1]	Seedling density (seedling/ha)	Total number of seedling (million)
Coastal	56	26	2,099	1,070.9
Hill	195	52	1,584	2,627.7
Sal	42	20	5,086	2,655.6
Sundarban	19	12	20,942	8,449.3
Village	110	41	413	4,275.6
National	278	63	1,419	19,079.1

[1]Unknown species or families were excluded.

Table 4.6: Seedling number by land cover, ranked by seedling density.

Land Cover Classes	No. of seedling species	Density (seedling/ha)	Total No. of seedlings (million)
Forest			
Plain Land Forest (Sal Forest)	10	23,361	985.2
Mangrove Forest	19	20,938	8,438.7
Forest Plantation	48	8,092	759.3
Mangrove Plantation	8	4,808	792.9
Bamboo Forest	1	2,037	10.2
Hill Forest	135	1,983	1,227.6
Shrubs with scattered trees	129	1,947	1,112.4
Rubber Plantation	14	807	40.1
Total Forest	**216**	**7,095**	**13,366.4**
Other Land (TOF)			
Shifting Cultivation	24	1,506	46
Rural Settlement	124	1,452	4,198.1
Orchards and Other Plantations (Trees)	20	1,049	20.8
Built-Up Non-Linear	12	741	6.2
Ponds	2	481	3.9
Herb Dominated Area	2	471	27.1
River Banks	3	448	10.6
Multiple Crop	37	155	492.8
Single Crop	49	140	637.1
Sand	1	120	16.6
Orchards and Other Plantations (Shrub)	8	110	10.7
Total Other Land	**160**	**473**	**5,469.9**

4.2.3 Recruitment Status by Species and Zone

Description

Understanding the patterns of survivorship is crucial for establishment and management of tree populations. As there is currently only one inventory cycle of the BFI, recruitment status was not calculated based on observed change in seedlings or saplings between two time periods, rather, the proportions of seedlings or saplings was reported. The seedling to tree recruitment was the percent of seedling density of total seedling and tree density by zone (seedling to tree recruitment = seedling / (seedling + tree)). The top 10 species ranked by stem density are given here, while recruitment estimates for all species can be found in the Appendix 4.2.3 (a,b).

The percentage of recruitment from seedling to sapling is comparable in all the 5 zones except Sal (Figure 4.3). In the Sal zone the sapling density is very little in comparison to tree density which resulted in a high recruitment percentage from sapling to trees but low percentage from seedling to sapling. This may indicate poor survival of the seedlings.

A. auriculiformis has the highest percent recruitment from seedling to tree, especially in the Village zone (Table 4.7).

Not shown are those species with very low recruitment. For example, for some fruit tree species (e.g. S. cumini) human management may be interfering with natural regeneration, resulting in a higher percentage of trees over saplings. Despite the large number of seedlings observed for *S. robusta* in the Sal zone (see 4.2.1), only a modest 1% seedling survival is observed.

Highlights

- Seedlings of *A. auriculiformis, A. richardiana* and *E. agallocha* are commonly occurring trees with high percentage recruitment to trees indicating low interference in growth for these species.
- Seedling to tree recruitment is especially high for *A. indica*in the Hill zone.
- *A. cucullata* and *C. mitis* (not shown) both have lower recruitment from seedling to tree, perhaps indicating less preference of these species by people living in the Village and Hill zones, respectively.

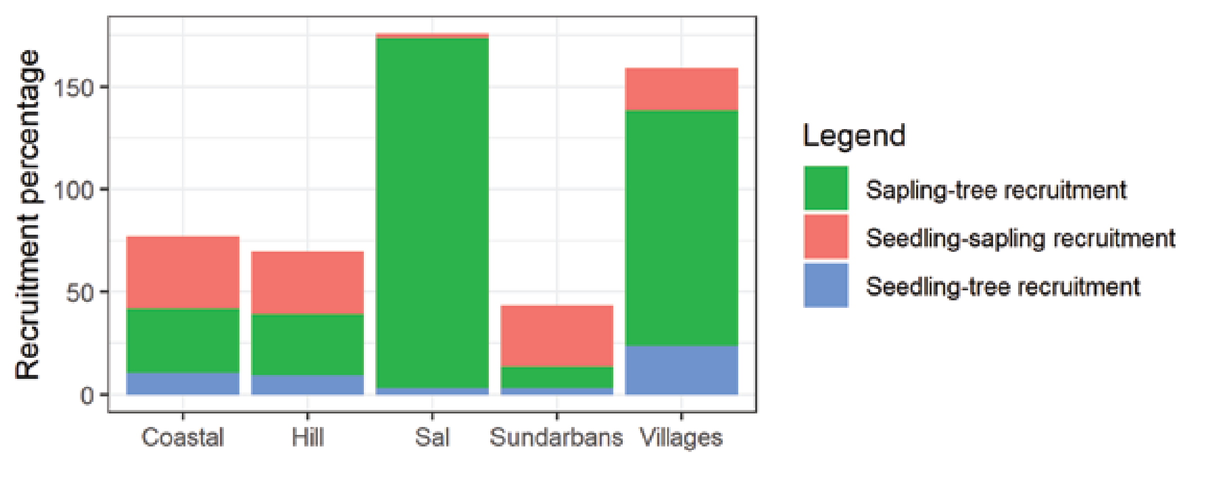


Figure 4.3: Recruitment percentage by zone.

Table 4.7: Recruitment status of 10 most dominant trees for seedling to trees recruitment only.

Scientific name	Seedling to tree recruitment percentage (%)	Recruitment percentages by Zones				
		CZ	HZ	SZ	SuZ	VZ
Sonneratia apetala	74.2	88.2			5.3	
Chukrasia tabularis	70.1		36.8			
Neolamarckia cadamba	41.7		10.8			61.4
Azadirachta indica	39		171.2	17.6		39.4
Albizia procera	31.6	30.5	31.3	6.6		34.8
Albizia richardiana	24	17.1	19.7			24.3
Acacia auriculiformis	22.8	11.5	13	15.6		54.3
Protium serratum	13.8		11.9			
Excoecaria agallocha	12.1	1			23.5	

4.3

Plant Diversity Index of Trees

Description

Several diversity indices were considered for quantifying trees diversity by zone, reflecting zones of lower or higher diversity. This is different than a plot level approach which would average the index over many plots. Four common diversity indices were used: Shannon-Wiener Diversity Index (SWDI), Simpson's Dominance index (SDI), Margalef's Richness index (MRI) and Pielou's Evenness index (PEI) following Shannon (1963), Simpson (1949), Margalef (1958) and Pielou (1966) respectively.

The Shannon-Wiener diversity index value indicated somewhat low tree diversity across the country. Yet, the Hill and Village zones have comparatively higher Shannon-Wiener diversity than in Coastal and Sundarban zones (Figure 4.4; Table 4.8). The dominance of a relatively fewer species in the Coastal and Sundarban zones (e.g. *E. agallocha* and *H. fomes*) is the reason for their lower diversities. The Margalef's Richness also indicated higher species richness in Village and Hill zones. Peilou's Evenness index, indicating the closeness of the population of each species, showed higher unevenness in the number of each species in the Hill zone.

Highlights

- The Hill and Village zones have the highest species diversity (SWDI) and species richness (MRI)
- The lowest species diversity and species richness occurs in the Sundarban zone.
- Relative abundance of the species is lowest in Hill zone (SDI).

Table 4.8: Plant diversity index by zone.

Zone	SWI	SDI	MRI	PEI
Coastal	1.990	0.318	9.439	0.428
Hill	3.984	0.054	24.316	0.705
Sal	2.737	0.151	11.485	0.578
Sundarban	1.403	0.296	2.187	0.417
Village	3.400	0.077	20.286	0.624
National	3.162	0.116	29.372	0.529

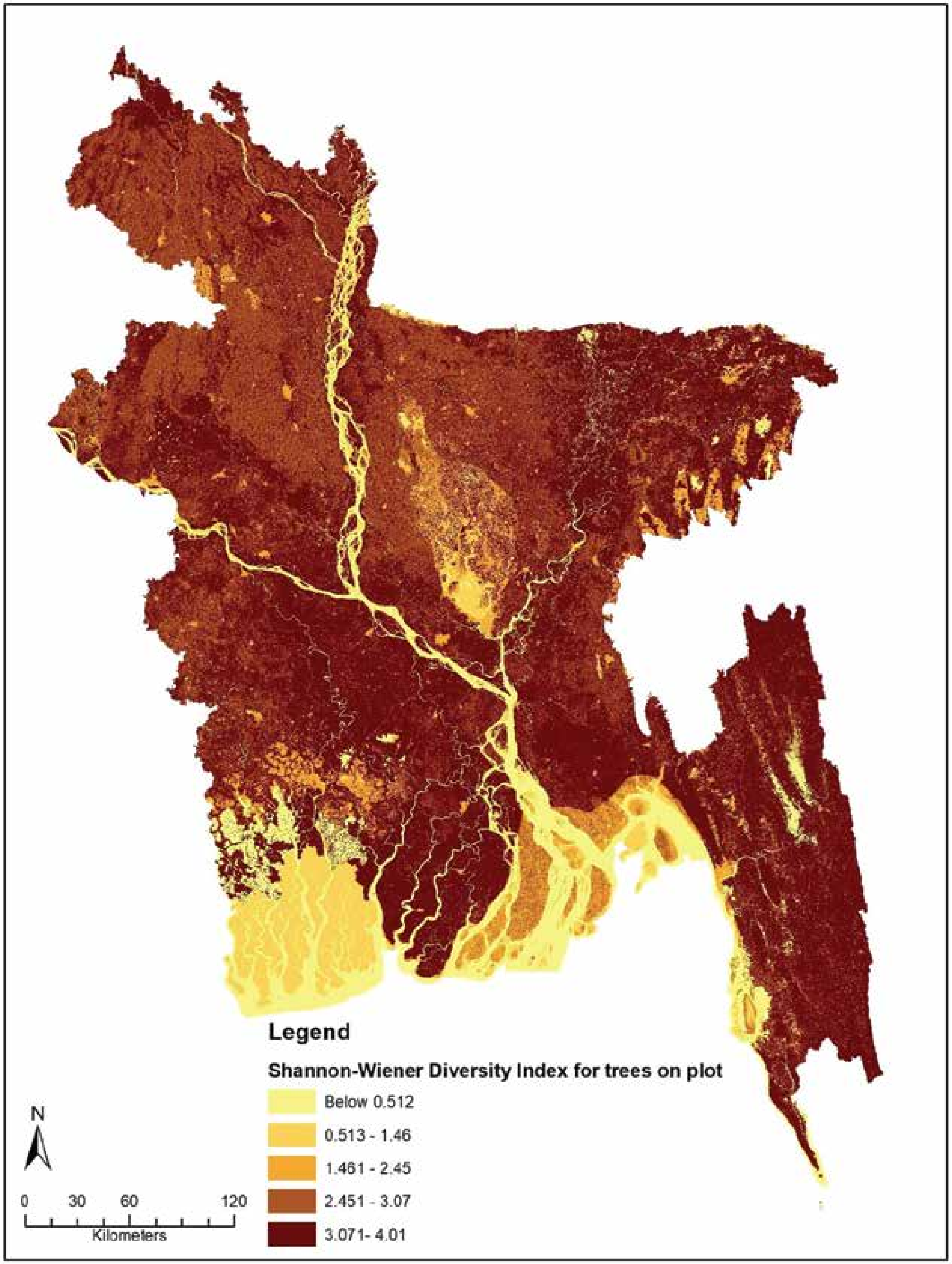


Figure 4.4: Map of the spatial distribution of Shannon-Weiner Index determine from BFI plots.

4.4

Status of Native and Introduced Tree Species

Description

Tree species that were introduced less than 250 years ago are considered to be introduced species (FAO 2018b). Introduced tree species were brought to Bangladesh at different times for purposes such as commercial timber productivity and improving site quality. Previously published literature (Davidson and Das 1985, Zabala 1990, Hossain and Pasha 2004, Akter and Zuberi 2009, Hossain and Hoque 2013) were used to identify the introduced tree species in BFI.

The stem densities presented refer to both sapling and trees. The more urbanized the zone, the larger proportion of introduced tree individuals, i.e. Village > Sal > Hill > Coastal > Sundarban (Figure 4.5). Though there are no introduced species found in the sample plots of the Sundarban zone, each of the remaining four zones harbored 20-30 introduced species. Though the distribution of introduced seedling individuals is comparable to the trees, the percentages of introduced seedlings are lower than the tree individuals (Figure 4.6).

Among the 24 land cover classes with presence of trees, comparatively more introduced species by tree density are found in Rubber Plantation, Rural Settlement, and Shifting Cultivation (Table 4.9). High percentages of introduced species are also inventoried in marginal areas around Ponds and Multiple and Single Crops (Table 4.9). At least 34 introduced species are found in Rural Settlement. There are a total of 36 introduced species inventoried among which *A. catechu* is most common (Table 4.10).

Highlights

- Rubber plantations have the highest density of introduced tree species though only 4 species are counted, indicating monoculture systems.

- The high number of introduced species in Rural Settlement suggests the popularity of planting these species in homestead gardens.

- The highest stem density of introduced species by zone is *T. grandis* in the Hill zone.

- The fast-growing *A. auriculiformis* (Sal zone, used for fuelwood), *A. catechu* (Hill zone, harvested for nuts), and *S. mahagoni* (Village zone, used for construction) are some of the notable introduced species of Bangladesh.

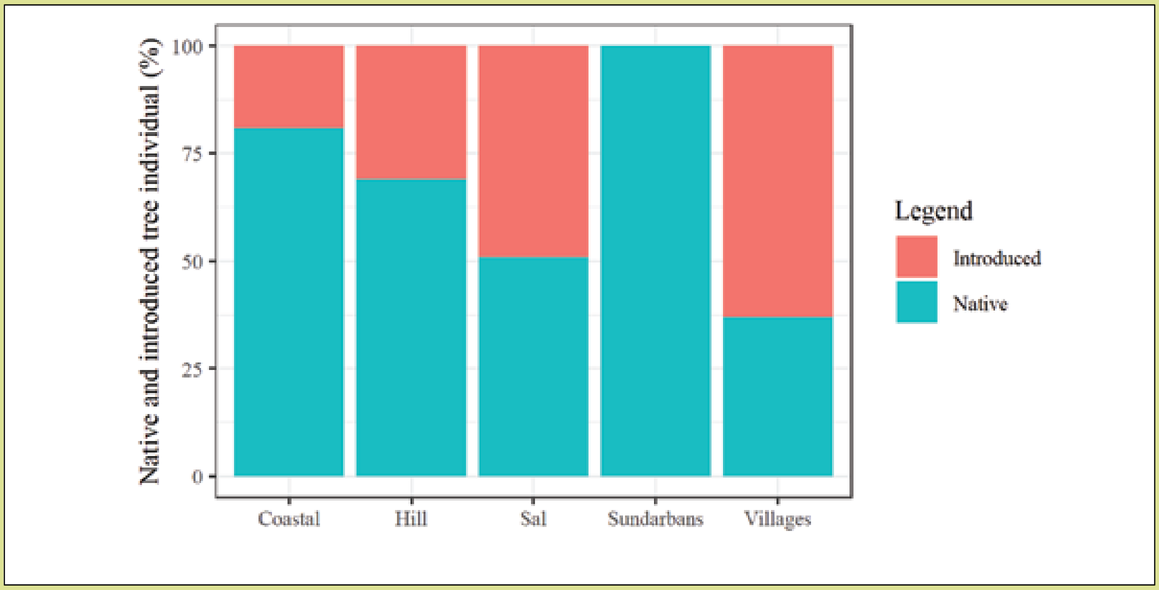


Figure 4.5: Percentage of native and exotic tree individuals in different zones.

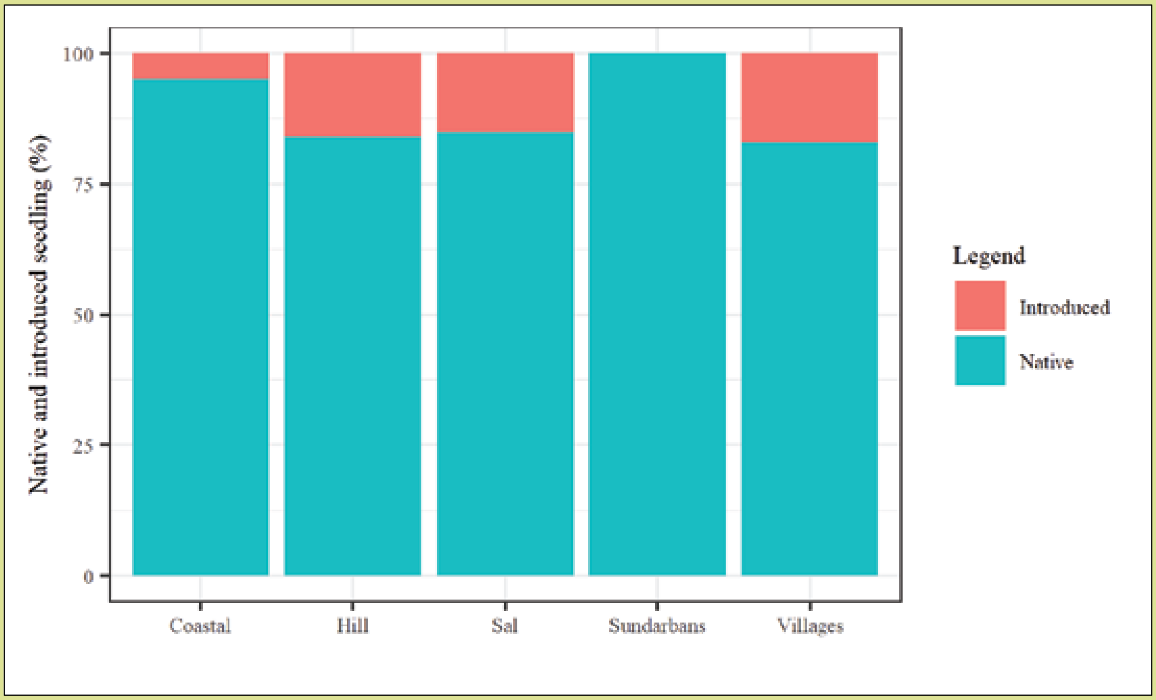


Figure 4.6: Percentage of native and exotic seedling individuals in different zones.

Table 4.9: Origin of tree species in different land cover classes, ranked by introduced species stem density.

Land Cover Classes	Species number		Percentage of total sapling and tree individuals		Tree and sapling density (stem/ha)	
	Native	Introduced	Native	Introduced	Native	Introduced
Forest						
Rubber Plantation	15	4	24.86	75.14	137.61	415.83
Forest Plantation	87	15	65.76	34.24	503.37	262.11
Shrubs with scattered trees	180	17	67.27	32.73	469.59	228.44
Hill Forest	223	18	72.15	27.85	568.29	219.4
Plain Land Forest (Sal Forest)	19	5	95.98	4.02	779.96	32.66
Bamboo Forest	2	0	100	0	111.81	0
Mangrove Plantation	13	0	100	0	2,155.72	0
Mangrove Forest	30	0	100	0	6,843.28	0
Other Land (TOF)						
Rural Settlement	238	34	36.18	63.82	209.14	368.93
Shifting Cultivation	35	5	70.57	29.43	847.7	353.58
Built-Up Non-Linear	24	14	23.61	76.39	54.59	176.62
Orchards and Other Plantations (Trees)	53	16	56.52	43.48	174.14	133.98
Ponds	5	4	52.79	47.21	130.75	116.93
Orchards and Other Plantations (Shrub)	31	8	64.67	35.33	94.47	51.61
Multiple Crop	79	20	31.77	68.23	17.7	38.01
Single Crop	110	25	45.31	54.69	22.37	27
River Banks	20	7	95.57	4.43	449.49	20.82
Fresh Water Aquaculture	6	7	34.72	65.28	5.24	9.85
Herb Dominated Area	3	4	44.6	55.4	7.42	9.22
Sand	1	2	0	100	0	0.3
Brickfield	3	0	100	0	3.35	0
Brackish Water Aquaculture	1	0	100	0	30.55	0
Mud Flats or Intertidal Area	2	0	0	0	0	0
Swamp Reed Land	2	0	100	0	91.98	0

Table 4.10: Complete list of introduced tree species densities by zone, ranked by stem density.

Scientific name	Local Name	Stem density (stem/ha)	Distribution of density into zones (tree/ha)				
			CZ	HZ	SZ	SuZ	VZ
***Areca catechu*[1]**	Supari	27	100.29	3.27	0.81		29.56
Swietenia mahagoni	Mahogony	26	15.25	1.48	15.58		31.44
***Tectona grandis*[1]**	Segun	15	0.02	116.73	4.69		0.56
Acacia auriculiformis	Akashmoni	15	1.14	39.43	64.89		9.76
Eucalyptus camaldulensis	Eucalyptus	9	0.20		2.78		11.34
***Artocarpus heterophyllus*[1]**	Kanthal	6	21.64	6.31	17.40		5.07
Samanea saman	Sirish	5	23.55	0.046	1.80		4.77
***Cocos nucifera*[1]**	Narikel	4	7.68	0.17	0.94		4.68
Albizia richardiana	Raj Koroi	4	3.94	1.47	0.85		4.64
Eucalyptus alba	Eucalyptus	2	0.40	1.08	1.87		2.54
Acacia mangium	Mangium	2	0.10	10.78	3.24		0.76
Swietenia macrophylla	Mehogoni	2					2.38
Psidium guajava	Peyara	2	3.26	1.08	3.70		1.77
Litchi chinensis	Lichu	1		0.46	0.54		1.57
Polyalthia longifolia	Debdaru	1	1.12		0.08		1.43
***Borassus flabellifer*[1]**	Tal	1	0.94	0.03	3.93		1.19
Hevea brasiliensis	Rubber	1		3.79	8.73		
Senna siamea	Minjiri	1		4.04			0.03
Dalbergia sissoo	Sissoo	0.4					0.47
Lagerstroemia speciosa	Jarul	0.3		0.48			0.29
Leucaena leucocephala	Ipil ipil	0.3	0.10	0.03			0.30
Acacia nilotica	Babla	0.3	0.81				0.31
Tamarindus indica	Tetul	0.3	1.57	0.01	0.15		0.24
Melia azedarach	Ghora nim	0.2	0.30	0.40			0.23
Eucalyptus citriodora	Eucalyptus	0.2	0.10	0.62			0.15
Delonix regia	Krishnachura	0.1	0.10	0.98			0.03
Anacardium occidentale	Kaju	0.1	0.90	0.47			0.03
Pinus kesiya	Saral	0.04			0.01		0.04
Acacia catechu	Khayer	0.03		0.03	0.08		0.02
Phyllanthus acidus	Amla	0.02		0.03	0.24		0.01
Morus alba	Tut	0.02					0.02
Alstonia macrophylla	Chhatim	0.02	0.10	0.03			0.01
Pithecellobium dulce	Khai-babla	0.004	0.12				
Adenanthera pavonina	Raktachandan	0.0005			0.01		

[1]These species are introduced but considered naturalized in Bangladesh.

4.5

Red List Tree and Animal Species

4.5.1 Density of Red List Tree Species

Description

The IUCN Red List of trees was used for identifying threatened trees in Bangladesh (IUCN 2018). However, the IUCN list is a global list, and the same status may not apply in the context of Bangladesh. The sources used to determine the status of the species in Bangladesh were Khan, Rahman *et al.* (2001), Ahmed, Begum *et al.* (2008).

Among the 22 tree species identified in the Red List, 11 are found in the biophysical inventory. H. fomes has the highest population density followed by *A. chittagonga* and *D. alatus*.

The spatial occurrence of many Red List species is concentrated in the Sundarban and Hill zones, however they also occur somewhat randomly in the Village zone (Figure 4.7).

Highlights

- 10 of the 11 species species identified from the IUCN list occur in the Hill zone.
- Considering the IUCN status, *Aquilaria malaccensis*, or Agar, and *Sonneratia griffithii*, a mangrove specie, are the only designated as Critically Endangered (Table 4.11).
- Four species were identified as threatened in both the IUCN and Bangladesh lists: *Dipterocarpus costatus, Knema bengalensis, Anisoptera scaphula, and Aglaia chittagonga*.
- *Heritiera fomes* has the largest density of Red List tree species is identified in the IUCN list, but is not identified as threathened in Bangladesh.

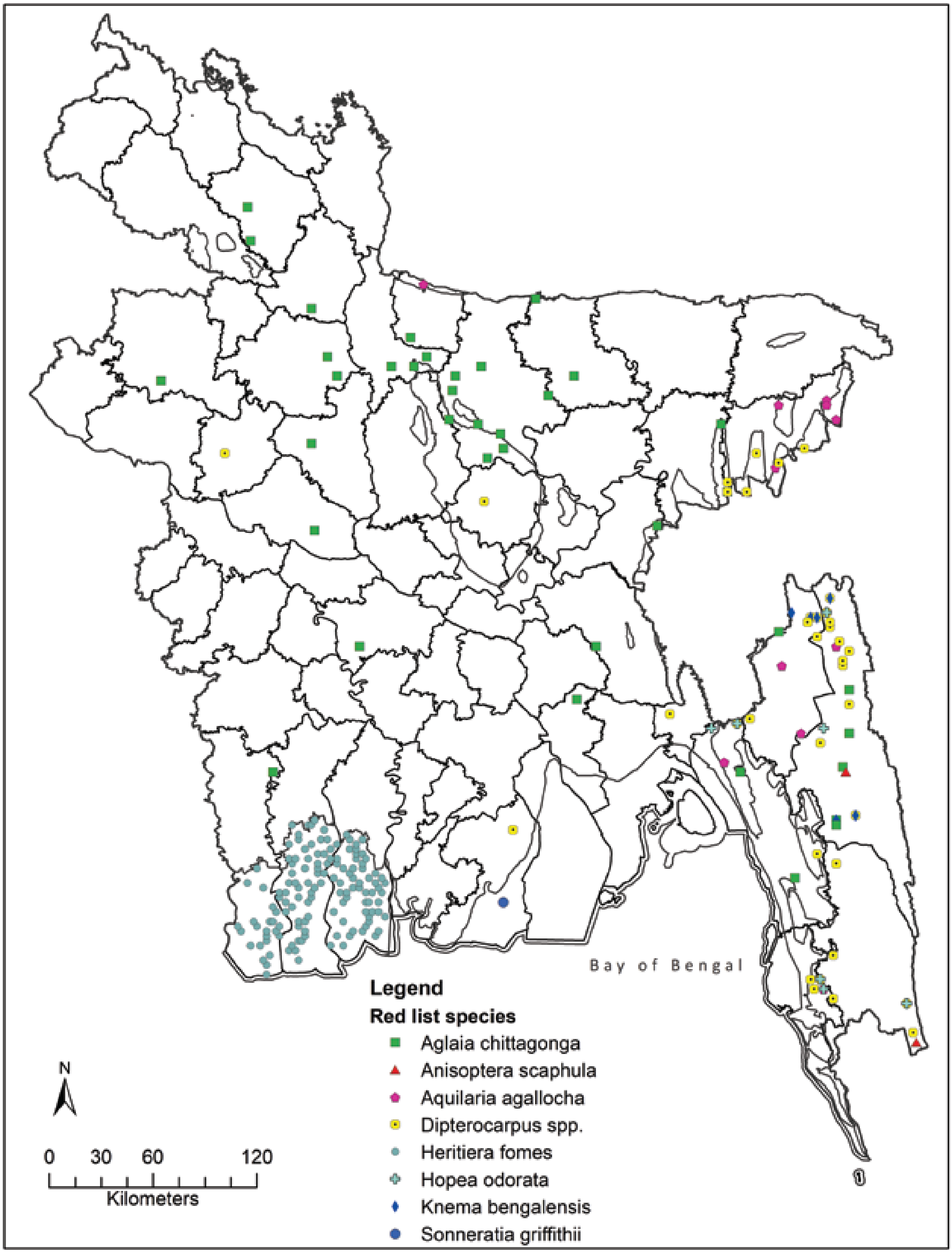


Figure 4.7: Spatial distribution of Red List tree species found in BFI plots.

Table 4.11: Density of the threatened tree species by zone.

Common name	Scientific name	Global Red List status[2]	Bangladesh status[1]	Density (stem/ha)	Distribution by zone (stem/ha)				
					CZ	HZ	SZ	SuZ	VZ
DholiGarjan	*Dipterocarpusalatus*	Vulnerable	Least Concern[3]	0.69		5.61			
BaittyaGarjan	*Dipterocarpuscostatus*	Vulnerable	Conservation Dependent[3]	0.08		0.63			
Arjan, DholiGarjan	*Dipterocarpusgracilis*	Vulnerable		0.02		0.10	0.03		0.01
Teliya Garjan	*Dipterocarpusturbinatus*	Vulnerable	Least Concern[3]	0.09		0.75			0.00
Agar	*Aquilariamalaccensis* (or *Aquilariaagallocha*)	Critically Endangered	Least Concern[3]	0.46		3.08	0.84		0.06
Khudiberala	*Knemabengalensis*	Vulnerable	Vulnerable[2]	0.09		0.73			
Choila	*Sonneratiagriffithii*	Critically Endangered		0.004	0.10				
Boilam	*Anisopterascaphula*	Endangered	Conservation Dependent[3]	0.01		0.07			
Sundri	*Heritierafomes*	Endangered		52.49		1.54		1743.57	
Titpasing	*Aglaiachittagonga*	Vulnerable	Conservation Dependent[3]	1.07	4.08	1.72	3.28		0.75
Telsur	*Hopeaodorata*	Vulnerable	Least Concern[3]	0.12		0.90			0.01

4.5.2 Red List Tree and Animal Species Traded

Description

The socio-economic survey and community questionnaire asked what animal and tree species were being hunted, collected, and traded by households. These were then matched with the species listed in the IUCN Red List for Extinct, Critically Endangered, Endangered, or Vulnerable categories (IUCN 2018). The sources used to determine the status of the species in Bangladesh were Khan, Rahman *et al.* (2001), Ahmed, Begum *et al*. (2008).

As the respondents used local common names to describe the tree and animal species, in some cases it is not possible to determine the exact species referred to. Therefore, all possible species and their status are listed for reference. In the case of turtle, although it is mentioned to be traded in the survey, it is not included because it is unknown if they were the same as Red List turtle species.

Among the 11 Red List plant species identified in the biophysical inventory, at least eight are found to be traded in Bangladesh (Table 4.12). It remains unclear, however, the exact species of Garjan that is mentioned to be traded.

At least four Red List animal species are mentioned to be traded in the survey (Table 4.13). They are considered threatened at some level both within and outside the country. The status of Gayal is mentioned to be endangered in Bangladesh in at least one study, though the designation is unofficial (Faruque *et al.* 2015) and it remains unclear the exact species.

Highlights

- The Hill zone is mentioned for all species except one as a place where Red List species are traded.
- The prevalence of Dipterocarpus indicates that this species remains vulnerable due to harvesting and trading for its many uses.
- Varanusbengalensis is also mentioned in the CITES Trade Database for Bangladesh exports (CITES 2019).

Table 4.12: Trees species that were mentioned tobe traded and identified as Red List species.

Common name	Zone	Scientific name	Bangladesh status[1]	Global Red List status[2]
Agar	Hill	*Aquilaria malaccensis* (or *Aquilaria agallocha)*	Unknown	Critically Endangered
Garjan	Hill	*Vatica lanceaefolia*	Unknown	Critically Endangered
		Dipterocarpus gracilis	Unknown	Vulnerable
		Dipterocarpus alatus	Critically Endangered	Vulnerable
		Dipterocarpus costatus	Critically Endangered	Vulnerable
		Dipterocarpus turbinatus	Critically Endangered	Vulnerable
Olive	All zones	*Elaeocarpus prunifolius*	Unknown	Vulnerable

[1]Khan, Rahman *et al*. (2001), Ara, Khan *et al*. (2013), Ahmed, Begum *et al.* (2015).
[2]IUCN (2018).

Table 4.13: Animal species that were mentioned tobe traded and identified as Red List species.

Common name	Zone	Scientific name	Bangladesh status[1]	Global Red List status[2]
Gayal (Gaur)	Hill	*Bos gaurus*	Extinct	Critically endangered
		Bos frontalis	Endangered	Unknown
Deer	Coastal Hill Sundarban periphery	*Muntiacus muntjak*	Endangered	Endangered
Monitor lizard/ Guisap	Hill Sal Sundarban periphery Village	*Varanus bengalensis*	Vulnerable	Nearly Threatened

[1]Khan, Rahman *et al.* (2001), Ara, Khan *et al.* (2013), Ahmed, Begum *et al.* (2008), Faruque, Rahaman *et al.* (2015).
[2]IUCN (2018).

Forest plantation, Tilagarh ©Zaheer Iqbal

Section 5:

Criteria 3 - Growing Stock, Biomass and Carbon

Swamp forest, Ratargul ©Zaheer Iqbal

Section 5

Criteria 3

Growing Stock, Biomass and Carbon

Section Highlights

- The most common native species by volume are *Mangifera indica* (Aam), *Heritiera fomes* (Sundri), *Sonneratia apetala* (Keora). The most common introduced species by volume are *Swietenia mahagoni* (Mahogany), *Areca catechu* (Supari), and *Cocos nucifera* (Narikel).
- TOF account for 66% of the country's total volume and 66% of the total biomass.
- Bamboos account for nearly 17% of the nation's total tree volume.
- There are 10,326 tons of dead wood considered usable as fuelwood (CWD, FWD, litter) and most of this stock is supplied by the Hill Forest (33%) and Rural Settlement (25%) land cover classes.
- The Sundarban zone contains extremely high densities of aboveground and belowground biomass carbon stocks, having 3.4 times and 9.6 times higher densities, respectively, than the national average. The total carbon density of all five carbon pools in the Sundarban is 345 t/ha (soil to 1m depth).

Introduction

This criterion describes the status, productive capacity, and spatial distribution of the country's trees and forests. It answers questions such as – in what species and in what areas are carbon stocks the highest? Growing stock is mostly used to indicate the availability of resources for commercial extraction. Biomass is the estimate of productive capacity of ecosystems and is useful for mapping. Carbon stocks indicate the contribution of the country's trees and forest to the global terrestrial carbon cycle. Changes in forest areas and land management impacts the rate of capture or release of carbon between terrestrial ecosystems and the atmosphere (e.g. Houghton 2005). Future inventory cycles will monitor the trends of these indicators over time. This section also contains estimates of TOF following the FAO definition, which is simply all trees that occur in the Other Land category in FAO's Global Forest Resource Assessment (Schnell *et al.* 2015; FAO, 2018). See Appendix 5 tables for details about which classes were aggregated to Forest and Other Land (i.e. TOF). Besides trees, estimates of dead wood biomass, soil carbon and other soil properties are presented.

Methods

Tree and saplings were surveyed in small, medium and large nested subplots (Section 2.3.3). Growing stock is volume over bark of all living trees with a minimum diameter of 10 cm at breast height (FAO 2018b). There were 28 species specific and one general volume equations used to estimate tree volume (see Appendix 2.3) (Hossain, Anik *et al*. 2019). Growing stock was estimated using total tree height (commercial volume was not estimated). Bamboos were recorded and measured in the medium (8 m radius subplot) plot. Bamboos were measured by average height, average DBH and number by clump. Bamboo culm volume was calculated directly using a general equation following Altrell (2007). All equations used are found in the Appendix 2.3 to 2.6 and Hossain, Anik *et al.* (2019).

There were seven species specific and four zone specific allometric equations used to estimate aboveground biomass. A decision tree was followed for appropriate selection of allometric equations (Hossain, Anik *et al*. 2019). Aboveground biomass includes biomass from live tree (DBH ≥ 10cm), saplings (DBH ≥ 2cm), bamboo and live stumps. The wood density at species level was collected from local sources found in Bangladesh's online wood density database (BFD 2016a) and other global sources. Genera or family level wood density was also used in cases when species level wood density was not available. Biomass from palms, such as *Areca catechu, Borassus flabellifer*, and *Phoenix sylvestris* which were recorded as trees during the biophysical survey were also included. Aboveground biomass was also estimated at the Forest Division level and is included in the Appendix 5.2.4.

Each of the five main carbon pools were estimated - above ground biomass, below ground biomass, down woody debris, litter and soil organic matter. Carbon in aboveground biomass was estimated with five species specific allometric equations and three zone-specific equations (Hill, Sal and Sundarban) and assumed 50% carbon content in wood, except for bamboo species which was assumed to be 54% (Allen 1986). Similar to volume and biomass, a decision tree was followed for proper selection of allometric models (BFD 2016a).

Carbon in belowground biomass (CBGB) includes all live plant parts including roots of trees, saplings, bamboos and live stumps. CBGB is estimated as 50% of BGB of trees, saplings, live stumps and bamboo. Below Ground Biomass (BGB) estimation procedure varied with the trees and saplings, stumps, bamboo and zones. In case of Sundarban tree and sapling DBH and species-specific wood density was used to calculate the BGB following Komiyama, Ong *et al.* (2008). For trees and saplings of other four zones the BGB was calculated from AGB following Pearson, Brown *et al.* (2007). A diameter based equation following Hjelm (2015) was used to calculate the BGB of live stumps, where the top diameter was used. Bamboo BGB is comparatively less and estimated following Lobovikov, Ball *et al.* (2007) for B.vulgaris and Bijaya and Bhandari (2008) for other bamboo species.

Dead wood biomass and carbon is composed of standing dead tree, dead stumps (and their belowground portion), coarse woody debris and fine woody debris, and carbon in biomass, litter, and soils. Dead stumps were calculated using a cylindrical volume equation (Jenkins, Chojnacky *et al.* 2003) and then volume was multiplied with species-specific or general wood densities to calculate biomass. Carbon in dead wood biomass assumed a carbon content of 50% of the dead wood biomass. The diameters of coarse woody debris (CWD) were measured along a transect to estimate CWD volume following Marshall, Davis *et al.* (2000). For fine woody debris (FWD) an average diameter was assumed for small, medium and large FWD and then the volume was estimated following Marshall *et al.* (2000) and summed up for getting total FWD volume by subplot. CWD and FWD wood density reductions were used to calculate their biomass (Jenkins, Chojnacky *et al.* 2003, Harmon, Woodall *et al.* 2011). Standing dead tree biomass was estimated using the height, DBH, decay status and reduced wood density and biomass models. The wood density reduction factor was calculated considering the wood decay classes prescribed in BFI manual and the raw data collected for allometric equation development (BFD 2016a, BFD 2016c). For litter, a sample collected from the field was processed in the laboratory and litter carbon was assessed multiplying the oven dry litter mass by its organic carbon percentage (BFD 2016d).

Soil samples were collected and analyzed for bulk density and soil organic carbon (SOC) density. Samples were collected from 0-15 cm and 15-30 cm depths from all zones whereas an additional sample from 30-100 cm depth was collected in Coastal and Sundarban zones. Soil organic carbon was estimated by plot and land feature using the bulk density and SOC percentage data (Donato, Kauffman *et al.* 2009, BFD 2016d). Soil organic carbon percentage was determined by loss on ignition (LOI) method without removing carbonates,

Estimates are presented by species, zone, land cover class, Forest Divisions, height class and DBH classes (Hossain, Anik *et al.* 2019). The Bangladesh National Herbarium Tree Species Database was used for tree species identification. When summary statistics are by species, only the ten most dominant species are shown whereas the complete list can be found in the Appendix 5.1 tables. Zone level estimations of volume, biomass, and carbon followed estimators prescribed for stratified random sampling (Hossain, Anik *et al*. 2019). For estimates by land cover class, the classes were assigned to the land feature of the biophysical inventory plot post hoc by overlaying the 2015 Land Cover Map onto the subplot perimeters and extracting the areas. The R code for the estimations can be found in the BFIS e-Library (see also Hossain, Anik *et al.* 2019). Note that all data were collected from the biophysical inventory, except in the case of Sections 4.6 to 4.7 which show data from the socio-economic survey. Cells were left blank where there was no sample of that condition and a 0 value indicates < 0.01 of the respective unit. Volume and biomass estimates for all families and species can be found in the Appendix 5.1 and 5.2 tables.

Maps were produced by applying the mean estimate by land cover class and zone to the polygons of the 2015 Land Cover Map. When there was no or little data for very small land cover areas, values were substituted from other classes.For example, as there was no plot occurring in Herb Dominated Area in the Coastal or Sal zones to estimate growing stock value, the value for Herb Dominated Area in the Village zone was substituted.

5.1

Growing Stocks

5.1.1 Growing Stocks by Native and Introduced Species

Description

Among the 392 tree species inventoried, there are 354 native species, or 90% of the total number (Section 4.4). Among all species, *S. mahagoni* was the most abundant (Table 5.1). *S. apetala* was another important species which almost exclusively occurs in the Coastal zone. In contrast, the third most dominant species, *M. indica* (mango), grows in all the zones except Sundarban.

Two palms, *C. nucifera* and *A. catechu*, are notably abundant. *A. catechu* occurs in every zone except Sundarban and most abundantly in the Village zone (Table 5.2). The popularity of some of these introduced species in homestead plantations is partly the reason for their high volumes. Growing stock estimates for all families and species can be found in the Appendix 5.1 tables.

Highlights

- The most common trees of each zone are Sundri in Sundarban, Keora in Coastal, Sal in Sal zone, Shegun (teak) in Hill zone, and Mehogoni in Village zone.
- The Sundarban and Coastal zones are dominated by native tree species whereas the Sal and Village zones have many introduced species.
- Overall, the top ten native and introduced species by volume possess 27% and 40% of total national tree volume, respectively (Section 5.1.2).

Table 5.1: Top ten native species ranked by total growing stocks. Common names are given below the scientific names.

Native species			Introduced species		
Species	Growing stock (m^3/ha)	Total growing stock (million m^3)	Species	Growing stock (m^3/ha)	Total growing stock (million m^3)
Mangifera indica (Aam)	1.77	23.75	*Swietenia mahagoni* (Mahagoni)	2.59	34.84
Heritiera fomes (Sundri)	1.75	23.57	*Areca catechu*[1] (Supari)	1.85	24.90
Sonneratia apetala (Keora)	1.00	13.39	*Cocos nucifera*[1] (Narikel)	1.84	24.77
Excoecaria agallocha (Gewa)	0.84	11.26	*Samanea saman* (Rain tree)	1.19	16.02
Albizia lebbeck (Kala koroi)	0.51	6.88	*Borassus flabellifer*[1] (Tal)	0.87	11.76
Bombax ceiba (Simul)	0.38	5.16	*Eucalyptus camaldulensis* (Eucalyptus)	0.87	11.69
Albizia chinensis (Chakua Koroi)	0.37	4.93	*Artocarpus heterophyllus*[1] (Kanthal)	0.76	10.27
Phoenix sylvestris (Khejur)	0.35	4.69	*Acacia auriculiformis* (Akashmoni)	0.58	7.84
Shorea robusta (Sal)	0.35	4.64	*Albizia richardiana* (Raj Koroi)	0.51	6.82
Dipterocarpus alatus (Sil Garjan)	0.33	4.39	*Eucalyptus alba* (Eucalyptus)	0.44	5.86

[1]These species are introduced but considered naturalized in Bangladesh.

Table 5.2: Top five species by zone and ranked by growing stock.

Scientific name	Local name	Growing stock (m^3/ha)	Origin
Coastal Zone			
Sonneratia apetala	Keora	25.60	Native
Areca catechu[1]	Supari	5.14	Introduced
Samanea saman	Siris	4.90	Introduced
Cocos nucifera[1]	Narikel	3.33	Introduced
Sonneratia caseolaris	Ora	1.61	Native
Hill Zone			
Tectona grandis[1]	Shegun	3.00	Introduced
Dipterocarpus alatus	Sil Garjan	2.65	Native
Gmelina arborea	Gamari	2.01	Native
Swintonia floribunda	Civit	1.54	Native
Schima wallichii	Kanak	1.31	Native
Sal Zone			
Shorea robusta	Sal	8.11	Native
Acacia auriculiformis	Akashmoni	5.19	Introduced
Borassus flabellifer[1]	Tali palm	3.16	Introduced
Artocarpus heterophyllus[1]	Kanthal	2.72	Introduced
Hevea brasiliensis	Rubber	2.63	Introduced
Sundarban Zone			
Heritiera fomes	Sundri	58.42	Native
Excoecaria agallocha	Gewa	26.44	Native
Xylocarpus mekongensis	Dhundol	4.06	Native
Avicennia officinalis	Baen	3.83	Native
Bruguiera sexangula	Kankra	1.35	Native
Village Zone			
Swietenia mahagoni	Mehogoni	3.13	Introduced
Cocos nucifera[1]	Narikel	2.19	Introduced
Areca catechu[1]	Supari	2.11	Introduced
Mangifera indica	Aam	2.04	Native
Samanea saman	Siris	1.27	Introduced

[1]These species were introduced but considered naturalized in Bangladesh.

5.1.2 Growing Stocks, National Estimate by Zone and Land Cover Class

Description

The total gross tree volume of the country is 383.92 million m^3. This amounts to 2.38 m^3 per person.

The national average gross volume is 28.5 m^3/ha (Table 5.3). By comparison, the national level volume reported in the NFA was only 14 m^3/ha (MoEF and FAO, 2007). However, in the NFA only one common volume equation was used compared to the 29 equations used in the BFI. When the same NFA equation was used in the BFI, the resulting mean volume was still higher at 26 m^3/ha. The difference between the two estimates may be due to differences in sample design and/or some growth between the two periods.

Among the five zones, the Sundarban zone has the highest volume density followed by Coastal zone (Figure 5.1; Table 5.3). However, the Village zone has the highest total tree volume due to its extent, containing 222 million m^3.

Among the 33 land cover classes, there are 22 which have trees (Table 5.4). The Mangrove Plantation and Mangrove Forest have the highest volume density (Table 5.4). Tree Orchards and Rural Settlement volume densitites are also substantial. In terms of total volume, the Rural Settlement and Hill Forest are the highest.

TOF are an important resource in Bangladesh however there was previously no national level estimate to quantify the growing stock until now. Although the volume density in Forest was 3 times greater than TOF, TOF have almost two times more total gross volume than Forest.

Highlights

- 58% of the country's total gross tree volume (m^3) occurs in the Village zone followed by 20% in the Hill zone (Figure 5.2).
- The Sundarban zone volume (m^3/ha) is 3.4 times higher than the national average and more than 4.6 times higher than the Village zone.
- Notably high volume densities within zones include Mangrove Plantation (Coastal), Forest Plantation (Hill zone) and Plain Land Forest (Village zone).
- TOF accounts for 66% of the country's total tree gross volume.

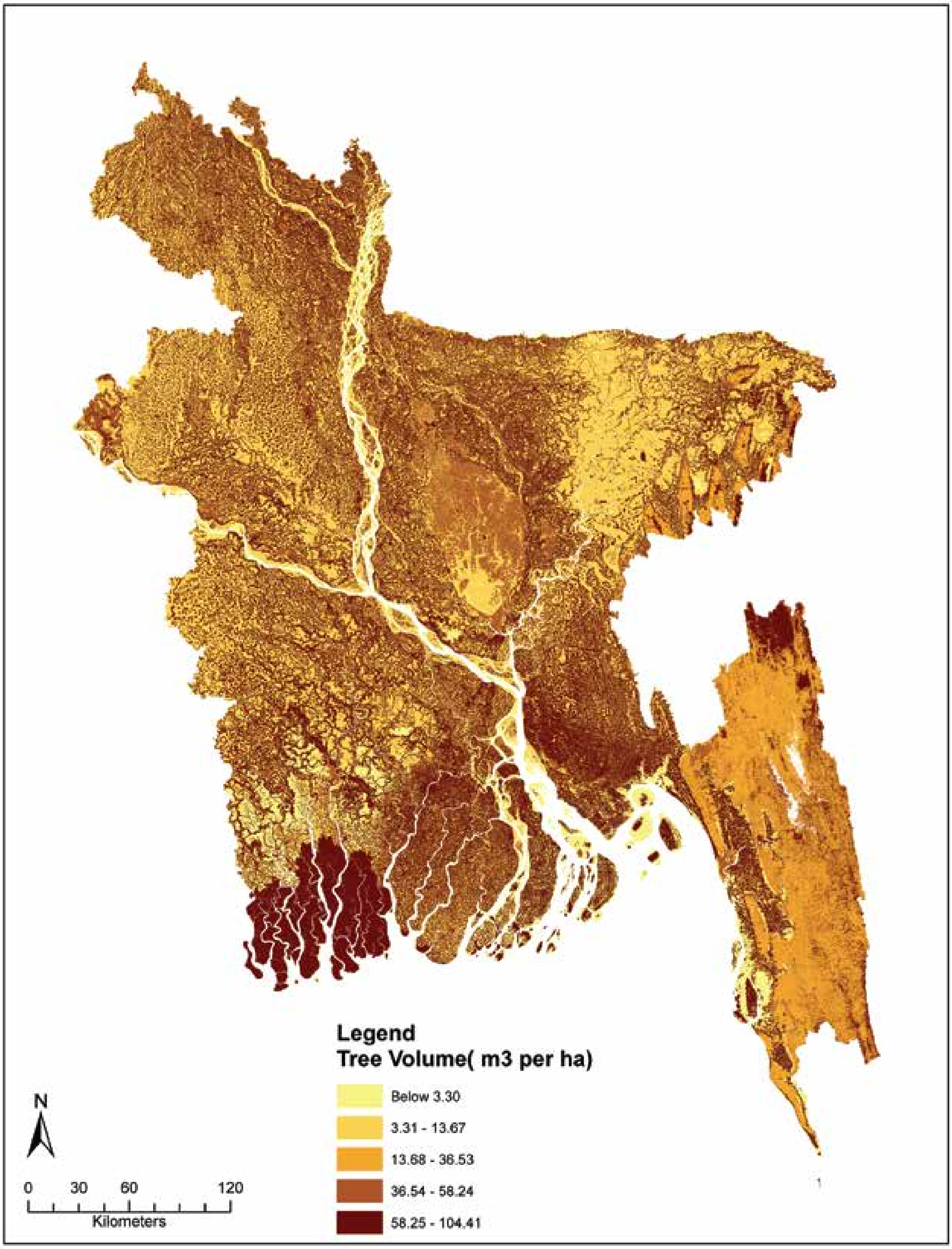


Figure 5.1: Spatial distribution of gross growing stock volume.

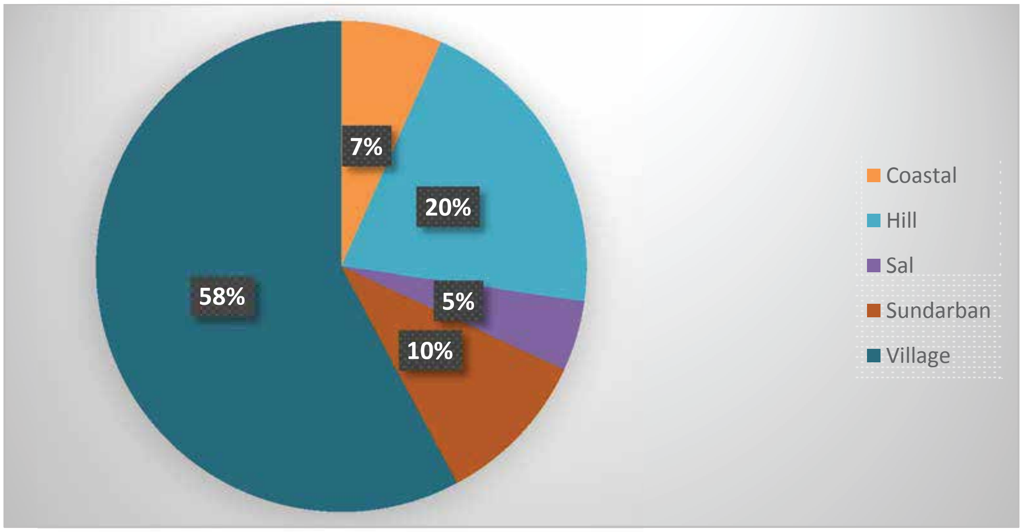


Figure 5.2: Percent total gross tree volume by zone.

Table 5.3: Gross tree volume by zone.

Zone	Volume (m^3/ha)	Total volume (million m^3)	Sampling error (±%)
Coastal	50.08	25.55	22.80
Hill	47.69	79.12	18.75
Sal	34.17	17.84	17.03
Sundarban	97.75	39.44	12.36
Village	21.44	221.98	10.85
National	28.54	383.92	7.67

Table 5.4: Gross tree volume by zone and land cover class, ranked by volume (m^3/ha).

Land Cover Classes	Volume (m^3/ha)	Total volume (1000 m^3)	Distribution of volume by zone (m^3/ha)				
			CZ	HZ	SZ	SuZ	VZ
Forest							
Mangrove Forest	97.85	39,436.74				97.85	
Mangrove Plantation	88.63	14,614.60	88.63				
Plain Land Forest (Sal Forest)	84.10	3,546.79			82.22		104.22
Hill Forest	82.77	51,232.49		83.77			5.89
Forest Plantation	65.95	6,188.85		83.14	45.15		
Rubber Plantation	51.68	2,566.93		36.53	81.00		
Shrubs with scattered trees	23.47	13,408.02	104.41	23.35	13.67		
Bamboo Forest	0.65	3.25		0.65			
Total Forest	**67.21**	**130,997.70**	**88.75**	**55.21**	**64.07**	**97.85**	**34.22**
Other Land (TOF)							
Rural Settlement	66.58	192,526.60	85.97	50.31	52.07		67.04
Orchards and Other Plantations (Trees)	56.84	11,266.76		25.69	64.36		58.14
Built-Up Non-Linear	37.54	3,126.53	58.24		4.45		40.41
Orchards and Other Plantations (Shrub)	36.85	3,595.71		29.51			99.06
River Banks	17.82	421.10		62.21	16.10	7.83	6.96
Swamp Reed Land	15.00	149.03					15.00
Ponds	13.42	108.09			46.80		
Shifting Cultivation	9.27	283.28		9.27			
Multiple Crop	5.86	18,657.42	2.42	10.54	7.92		5.78
Single Crop	4.91	22,285.83	2.17	8.29	10.70		4.73
Brickfield	3.20	80.99					3.30
Fresh Water Aquaculture	2.82	316.52	16.1				2.47
Herb Dominated Area	1.31	75.34			0.70		1.48
Sand	0.24	33.11					0.24
Total Other Land (TOF)	**21.99**	**252,926.30**	**31.39**	**23.39**	**27.04**	**7.83**	**21.42**

5.1.3 Growing Stocks by Diameter Class and Height Class

Description

Tree diameters were grouped into 10 classes, and there were few trees having more than 100 cm DBH. The highest volume density occurs in the 10 - <20 cm DBH class and was closely followed by the 20 - <30 class (Figure 5.3; Table 5.5). The greatest proportion of growing stock density within the first two classes was found in the Sundarban zone, however it was more equally distributed among zones for larger classes. In the Sal zone there are no trees having ≥80 cm DBH. However, Hill, Sundarban and Village zones have trees in all diameter classes.

Tree heights were also grouped into 10 classes. Growing stock density reached a maximum in the 10-<15 m height class indicating higher occurrence of trees in this class (Figure 5.4; Table 5.6). Similar to DBH classes, the Sundarban zone has the highest growing stock in the lower height classes. The height range 10-<20m has maximum volume density in all zones except Sundarban.

Highlights

- Trees with DBH < 40 cm make up 80% of the total tree volume.
- Nearly 90% of the total volume is made up of trees with heights less than 20m.
- The Sundarban zone has comparatively higher DBH trees due to the presence of species such as *H. fomes* and *E. agallocha* (Section 5.1.1).

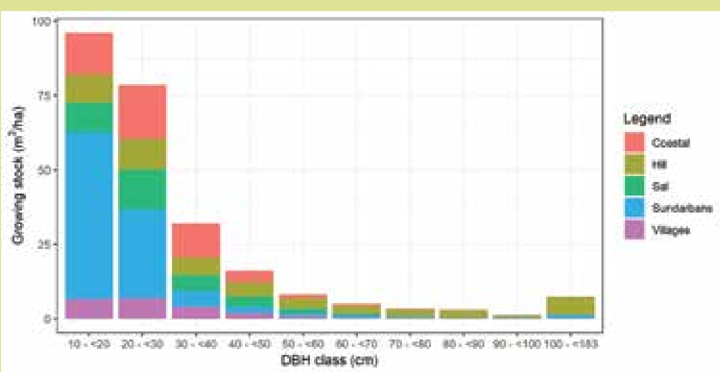


Figure 5.3: Growing stock by DBH class and zones.

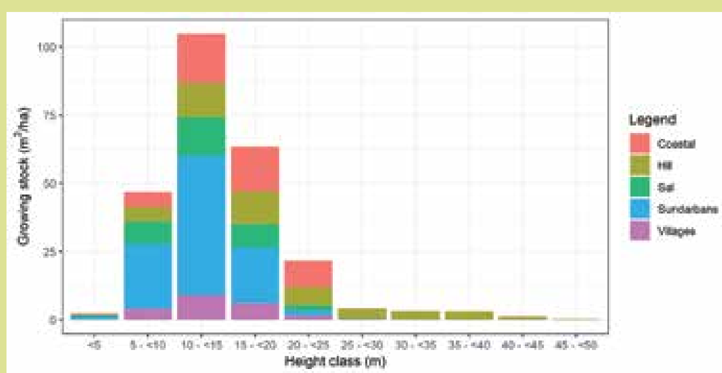


Figure 5.4: Growing stock by height class and zone.

Table 5.5: Growing stock by DBH class and zones.

DBH class	Volume (m^3/ha)	Total volume (million m^3)	Distribution of GS by Zone (m^3/ha)				
			CZ	HZ	SZ	SuZ	VZ
10-<20	8.76	117.87	14.02	9.42	9.95	56.16	6.49
20-<30	8.60	115.77	18.18	10.18	13.46	29.88	6.81
30-<40	4.67	62.84	11.35	6.02	5.19	5.36	4.074
40-<50	2.44	32.88	3.89	4.71	3.48	2.12	1.97
50-<60	1.26	16.95	1.50	3.41	1.46	1.02	0.90
60-<70	0.73	9.80	0.62	2.61	0.54	0.78	0.44
70-<80	0.57	7.73	0.33	2.23	0.09	0.39	0.35
80-<90	0.40	5.41	0.12	2.42		0.34	0.12
90-<100	0.19	2.56	0.07	0.64		0.47	0.12
≥ 100	0.90	12.11		6.06		1.23	0.15

Table 5.6: Gross volume by height class and zone.

Height class	Volume (m^3/ha)	Total volume (million m^3)	Distribution of GS by Zone (m^3/ha)				
			CZ	HZ	SZ	SuZ	VZ
<5	0.32	4.30	0.42	0.21	0.60	0.84	0.30
5-<10	4.98	67.00	5.51	5.19	8.35	23.72	4.02
10-<15	11.32	152.19	18.05	12.55	14.16	50.98	9.10
15-<20	7.80	104.94	16.36	11.93	8.75	20.19	6.19
20-<25	2.49	33.54	9.63	6.68	1.87	1.96	1.52
25-<30	0.66	8.89	0.02	3.62	0.32		0.26
30-<35	0.40	5.41	0.02	3.01	0.08		0.04
35-<40	0.38	5.11		3.04			0.01
40-<45	0.15	1.98	0.07	1.16	0.04		
≥ 45	0.04	0.55		0.30		0.06	0.00

5.1.4 Bamboo Stock, National Estimate by Zone and Land Cover Class

Description

Most of the bamboo volume occurs in the Village zone (68% of the total national bamboo volume), even though the Bamboo forest type by definition never occurs in this zone (Section 3.1) (Table 5.7). In terms of bamboo volume density (m^3/ha), the Hill zone is 2.6 times higher than the Village zone.

Bamboos occur in 14 land cover classes (Table 5.8). *Melocanna beccifera* mainly grows in the Hill zone whereas *Bambusa vulgaris* was the main bamboo in Rural Settlement (Appendix 5.1.1a). Not surprisingly, bamboo volume was highest in the Bamboo Forest and Hill Forest land cover classes. However somewhat surprising are that Orchard and Other Tree Plantations and Rural Settlement have medium bamboo volume densities. Rural Settlement by itself holds the most bamboo volume. Similarly, River Banks, and Multiple and Single Crop each have bamboo occurring at their margins, though the density was low.

Highlights

- Bamboo volume is about 17% of the country's total tree volume (Section 5.1.2).
- The most common bamboo species are *Bambusa vulgaris* and *Melocanna baccifera*.
- The Rural Settlements land cover class contains 59% of the total bamboo volume.
- Though Bamboo Forest has highest bamboo density it possesses less than 1% of the total bamboo stock due to the small spatial extent of this land cover class.

Table 5.7: Bamboo volume by zone.

Zone	Volume (m^3/ha)	Total volume (1000 m^3)	Sampling Error (±%)
Coastal	0.14	73.94	112.09
Hill	11.06	18,346.99	32.80
Sal	3.83	1,999.85	62.07
Village	4.19	43,406.56	27.64
National	4.75	63,827.34	21.12

Table 5.8: Bamboo volume by land cover class.

Land Cover Classes	Volume (m^3/ha)	Total volume (m^3)
Forest		
Bamboo Forest	26.15	131,288.11
Hill Forest	23.86	14,765,782.74
Shrubs with scattered trees	3.25	1,855,935.83
Forest Plantation	1.1	103,623.90
Total Forest	**8.95**	**16,856,630.58**
Other Land (TOF)		
Orchards and Other Plantations (Trees)	15.65	3,102,210.05
Rural Settlement	13	37,598,496.21
Shifting Cultivation	8.09	247,098.94
River Banks	4.06	96,016.18
Plain Land Forest (Sal Forest)	1.33	56,148.94
Single Crop	0.77	3,518,343.13
Multiple Crop	0.72	2,286,961.29
Sand	0.31	43,616.13
Fresh Water Aquaculture	0.16	17,915.60
Orchards and Other Plantations (Shrub)	0.04	3,904.11
Total Other Land (TOF)	**3.65**	**46,970,710.58**

Bamboo rafting, Kassalong, Rangamati ©*Zaheer Iqbal*

5.2

Tree Biomass

5.2.1 Above Ground Biomass by Species

Description

Certain tree species dominate their respective zones. Here, the top five species in aboveground biomass in each zone were ranked (Table 5.9). The local names of the most dominant species per zone are well recognized by the people living within them – Keora (Coastal), Shegun (Hill), Kanthal (Sal), Sundri (Sundarban), and Mahagoni (Village).

Biomass will often show the same patterns of spatial distribution as volume. For example, similar to volume, *H. fomes* has the highest above ground biomass in the Sundarban (Table 5.9). *S. mahagoni* was the highest introduced species, occurring mostly in the Village zone. *E. agallocha* was a top five species in both the Coastal and Sundarban zones. Aboveground biomass estimates for all species can be found in the Appendix 5.2.1.

Highlights

- *H. fomes* and *S. apetala* each dominate in their respective zones, having 4.0 and 2.4 times higher biomass than any other species in their respective zones.
- *M. indica* is a top species in both the Sal and Village zones, indicating its popularity as a planted tree.
- In contrast to other zones, no single species in the Village and Sal zones dominated as species there are more evenly distributed and diverse (see Section 4).

Table 5.9: Above ground biomass by species, ranked by top five occurrence in each zone.

Species	Local name	AGB (t/ha)
	Coastal	
Sonneratia apetala	Keora	20.52
Samanea saman	Rain tree	5.14
Areca catechu	Supa	4.27
Cocos nucifera	Narikel	2.24
Excoecaria agallocha	Gewa	2.21
	Hill	
Tectona grandis	Shegun	5.74
Gmelina arborea	Gamar	1.45
Albizia procera	Sada koroi	1.25
Dipterocarpus alatus	Dholi Garjan	1.24
Acacia auriculiformis	Akashmoni	1.03
	Sal	
Artocarpus heterophyllus	Kanthal	7.72
Hevea brasiliensis	Rubber	6.42
Borassus flabellifer	Tali	6.37
Shorea robusta	Sal	5.73
Mangifera indica	Aam	5.27
	Sundarbans	
Heritiera fomes	Sundri	56.01
Excoecaria agallocha	Gewa	23.17
Avicennia officinalis	Baen	5.70
Ceriops decandra	Goran	4.72
Xylocarpus mekongensis	Passur	2.80
	Village	
Swietenia mahagoni	Mahagoni	2.21
Mangifera indica	Aam	2.08
Areca catechu	Supari	1.46
Cocos nucifera	Narikel	1.40
Samanea saman	Rain tree	1.30
	National	
Mangifera indica	Aam	1.93
Swietenia mahagoni	Mahagoni	1.90
Heritiera fomes	Sundri	1.68
Areca catechu	Supari	1.31
Samanea saman	Rain tree	1.27

5.2.2 Above Ground Biomass, National Estimate by Zone and Land Cover Class

Description

The above ground biomass density is highest in Sundarban (98.37 t/ha) perhaps due to its high stem density (Figure 5.5; Table 5.10; see also Section 4.1.1) and is 3.4 times higher than the national average. Similar to tree volume, the aboveground biomass density (t/ha) is lowest in the Village zone, yet it contains the highest total amount of biomass.

The national average aboveground biomass across the zones is 28.78 t/ha (Table 5.10). By comparison, the national level biomass reported in the NFA was 57 t/ha (MoEF and FAO, 2007). However, in the NFA, one common volume equation and biomass expansion factor were used for the estimation compared to the 11 biomass equations used in the BFI. When the same NFA equation is used in the BFI, the resulting mean volume is 88 t/ha. The difference between the two estimates may be due to differences in sample design or some growth between the two periods. See Appendix tables for more NFA comparisons.

Among the 22 land cover classes where trees occur, aboveground biomass density is highest in the Mangrove Forest (Table 5.11). The Rural Settlement is highest in total stocks, containing about 50% of the total country's biomass.

Notably high values among land cover and zones include Mangrove Plantations (Coastal), Forest Plantation (Hill), Rubber Plantations (Sal), and Plain Land Forest (Village).

Biomass density in Forest is three times higher than in TOF. Yet, TOF have almost two times higher total biomass.

Highlights

- TOF contain 66% of the total biomass stock.
- The Sundarban zone has the highest biomass density (t/ha), about five times higher than the Village zone.
- Plain Land Sal Forest biomass density (t/ha) is 3.3 times higher than the national average.
- Rubber Plantation in the Sal zone have extremely high biomass density (198 t/ha).
- The highest biomass density by land cover occurring in the Hill zone is Hill Forest followed by Forest Plantations.

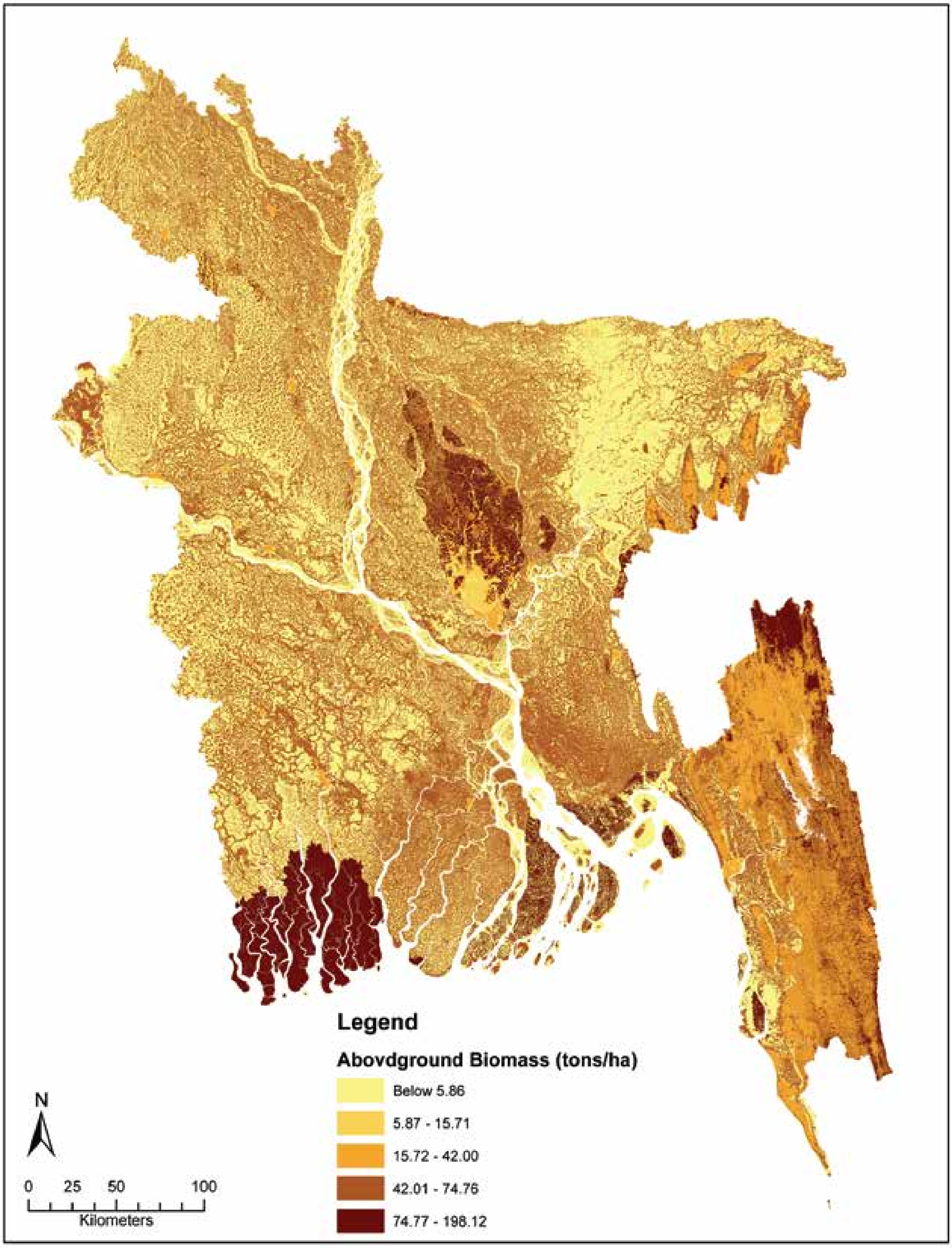


Figure 5.5: The spatial distribution of biomass stocks.

Table 5.10: Above ground biomass by zones.

Zone	AGB (t/ha)	Total AGB (million t)	Sampling Error (±%)
Coastal	43.63	22.26	20.25
Hill	48.32	80.15	14.27
Sal	59.43	31.03	17.14
Sundarban	98.37	39.69	8.18
Village	20.66	213.97	10.12
National	28.78	387.09	6.63

Table 5.11: Above ground biomass by land cover class and zone.

Land Cover Classes	AGB (t/ha)	Total AGB (1000 t)	Distribution of AGB into Zones (t/ha)				
			CZ	HZ	SZ	SuZ	VZ
Forest							
Mangrove Forest	98.34	39,633.33				98.34	
Rubber Plantation	95.19	4,728.14		42	198.12		
Hill Forest	82.76	51,222.09		83.38			34.79
Mangrove Plantation	74.76	12,328.46	74.76				
Plain Land Forest (Sal Forest)	67.06	2,828.23			66.86		69.21
Forest Plantation	58.52	5,491.15		63.07	53.78		0
Bamboo Forest	33.15	166.39		33.15			
Shrubs with scattered trees	27.06	15,459.94	87.72	27.03	12.25		0
Total Forest	**67.66**	**131,857.73**	**74.86**	**56.11**	**81.32**	**98.34**	**42.67**
Other Land (TOF)							
Orchards and Other Plantations (Trees)	70.41	13,957.97		23.15	135.99		64.43
Rural Settlement	66.27	19,1622.1	77.96	50.97	101.46		64.22
Ponds	31.52	253.87			109.91		0
Orchards and Other Plantations (Shrub)	28.06	2,738.23		22.86			72.11
Built-Up Non-Linear	25.4	2,115.74	45.46		11.57		26.12

Land Cover Classes	AGB (t/ha)	Total AGB (1000 t)	Distribution of AGB into Zones (t/ha)				
			CZ	HZ	SZ	SuZ	VZ
Other Land (TOF)							
Swamp Reed Land	25.37	252.05					25.37
Shifting Cultivation	24.28	741.70		24.28			
River Banks	19.12	451.94		56	41.65		5.86
Multiple Crop	5.9	18,778.67	2.4	10.66	15		5.5
Single Crop	5.24	23,819.92	2.19	8.43	24.41		4.76
Fresh Water Aquaculture	2.59	291.37	15.71				2.25
Herb Dominated Area	1.79	102.91	0		1.74		1.97
Brickfield	1.62	41			0		1.67
Sand	0.45	62.48					0.45
Brackish Water Aquaculture	0.03	1.13					0.03
Mud Flats or Intertidal Area	0.03	0.67	0.03				0
Total Other Land (TOF)	**22.19**	**255,231.80**	**28.53**	**23.14**	**54.21**	**0.00**	**20.64**

Oven dried leaf, Nutrient dynamics lab, Khulna University *©Falgoonee Kumar Mondal*

5.3

Dead Wood Biomass and Potential Fuelwood

Description

Dead wood and litter biomass is important to ecosystem function and stores carbon (Section 5.4). It is also major source of fuel for households (see Section 9.5.1). The main pools of dead biomass used for fuel are coarse woody debris (CWD), fine woody debris (FWD), and litter.

The dead wood biomass across the zones is 0.89 t/ha and varied greatly among zones (Table 5.12). The Sundarban zone shows the highest dead wood biomass density which is 5.7 times higher than the national average. Low fuel wood collection, natural disasters (e.g. cyclones) and top dying of Sundri are potential reasons for high dead wood biomass in the Sundarban and Coastal zones. Standing dead tree and FWD biomass density is highest in Sundarban whereas dead stump is highest in the Coastal and CWD in the Hill zone.

Dead wood and litter biomass used as fuel (CWD, FWD, litter) occurs in 22 land cover classes among which Mangrove Plantations, Shifting Cultivation, Hill Forest, and Mangrove Forest showed the highest biomass density (Table 5.13). The high values for Shifting Cultivation indicate the large amounts of CWD and FWD that are left behind after cutting the trees. Hill Forest, Rural Settlement and Shrubs with scattered trees have the highest total volume, indicating these as major suppliers of dead wood potentially used for fuel. Notably low amounts are found near urban areas and areas surrounding the Sundarban (Figure 5.6).

Highlights

- The Hill zone has 43% of the total dead wood and litter biomass followed by Village zone at 26%.
- The high dead wood and litter biomass density in the Coastal and Sundarban zones may indicate lower pressure from collection (e.g. more difficult access) (see Section 9.5).
- There is 10,326 tons of dead wood that could potentially be used for fuel (CWD, FWD, litter) and 33% of this is supplied by Hill Forest while 25% is supplied by Rural Settlement.

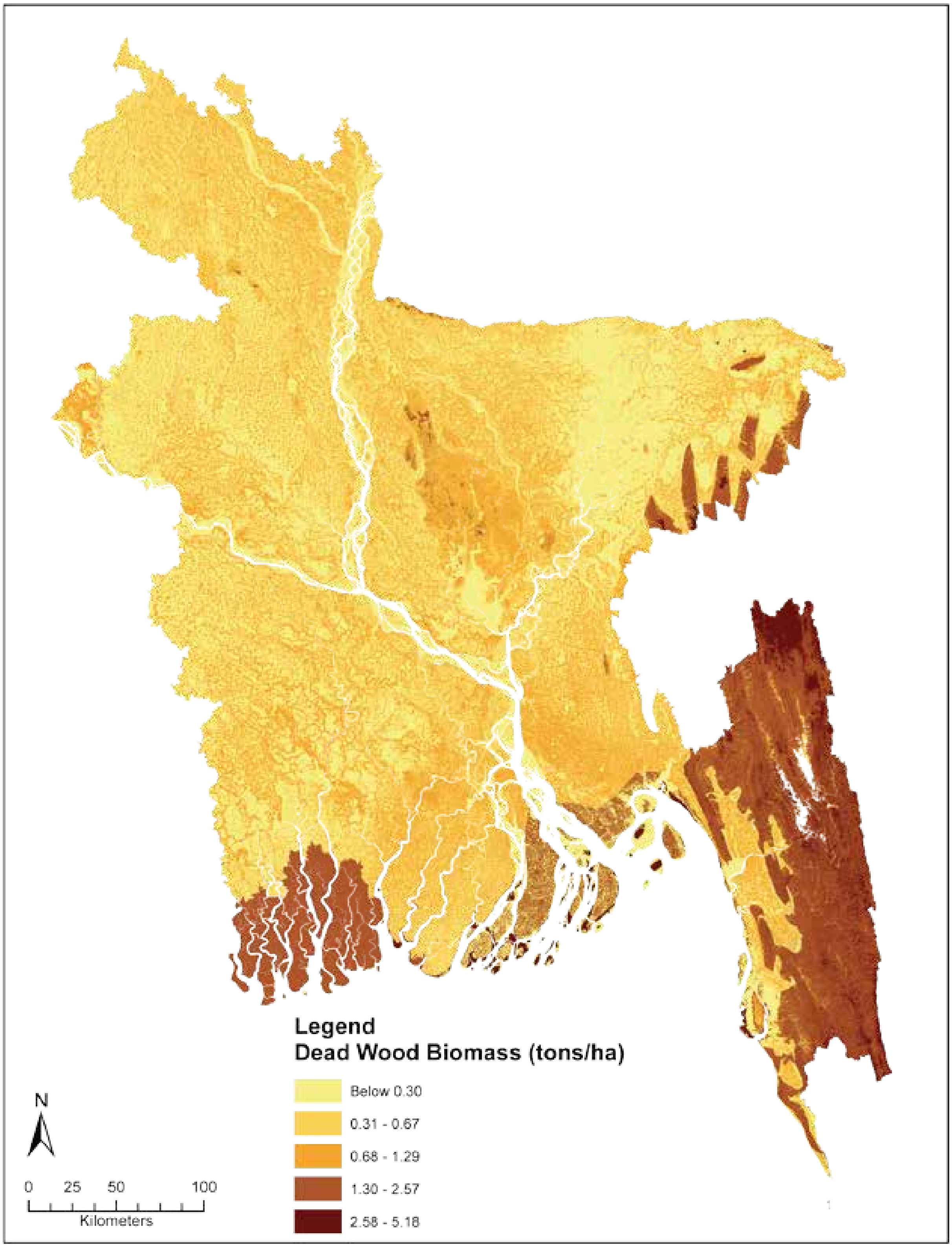


Figure 5.6. Spatial distribution of dead wood (CWD, FWD and litter) biomass.

Table 5.12: Dead biomass and standard errors by zone.

Zone	Standing dead tree		Dead Stump		CWD		FWD		Litter		All Dead Biomass (t/ha)	Total Dead Biomass (Million t)
	Biomass (t/ha)	SE (±%)	Biomass (t/ha)	SE (±%)	Biomass (t/ha)	SE (±%)	Biomass (t/ha)	SE (±%)	Biomass (t/ha)	SE (±%)		
Coastal	0.69	73.27	0.16	61.53	0.66	89.96	0.92	23.27	0.11	36.80	2.43	1.24
Hill	0.50	72.43	0.10	27.82	1.23	45.43	1.24	6.00	0.57	10.69	3.06	5.08
Sal	0.23	72.35	0.02	105.98	0.01	195.87	0.64	15.38	0.33	25.12	0.89	0.46
Sundarban	3.03	26.48	0.11	53.70	0.42	35.14	1.54	5.93	0.32	15.72	5.10	2.06
Village	0.05	34.44	0.01	43.58	0.01	111.90	0.23	14.62	0.05	19.12	0.30	3.10
National	0.23	24.75	0.03	21.33	0.19	37.57	0.44	6.67	0.14	8.36	0.89	11.93

Table 5.13: Dead wood biomass that could potentially be used for fuel (i.e. CWD, FWD and Litter) by land cover class and zone, ranked by total biomass.

Land Cover Class	CWD, FWD and Litter (t/ha)	Total (t)	Distribution of CWD, FWD, and Litter into zones (t/ha)				
			CZ	HZ	SZ	SuZ	VZ
Forest							
Hill Forest	5.16	3407.78		5.18			4.27
Shrubs with scattered trees	1.82	986.66	1.07	1.83	0.67		0
Mangrove Forest	2.28	919.62				2.28	
Mangrove Plantation	3.49	579.23	3.49				
Forest Plantation	2.25	222.05		2.57	1.92		0
Rubber Plantation	1.93	108.03		2.09	1.64		
Plain Land Forest (Sal Forest)	1.97	80.72			2.01		1.00
Bamboo Forest	2.28	12.67		2.28			
Total Forest	**0.0034**	**6316.76**	**3.11**	**3.55**	**1.86**	**2.28**	**0.89**
Other Land (TOF)							
Rural Settlement	0.93	2586.83	2.14	1.41	1.29		0.85
Single Crop	0.12	579.95	0.18	0.65	0.44		0.10
Multiple Crop	0.10	341.77	0.06	0.55	0.34		0.09
Orchards and Other Plantations (Trees)	1.13	233.77		1.95	1.78		0.95
Orchards and Other Plantations (Shrub)	1.57	157.17		1.64			0.76
Shifting Cultivation	1.94	51.14		1.94			
Built-Up Non-Linear	0.34	32.09	1.60		0.26		0.30
River Banks	0.38	8.46		1.75	0		0.06
Fresh Water Aquaculture	0.06	7.62	0.05				0.06
Brackish Water Aquaculture	0.08	2.98					0.08
Swamp Reed Land	0.22	2.20					0.22
Ponds	0.24	1.92			0.83		0
Herb Dominated Area	0.03	1.65	0		0.58		0
Mud Flats or Intertidal Area	0.05	1.39	0.05				0.00
Total Other Land (TOF)	**0.0003**	**4008.94**	**0.32**	**1.01**	**0.73**	**0.00**	**0.30**

CZ: Coastal zone, HZ: Hill zone, SZ: Sal zone, SuZ : Sundarban zone, and V: Village zone.

5.4

Carbon

5.4.1 Carbon Pools, National Estimate by Zone

Description

Most of the carbon stock is contained in the top 30 cm of the soil (80%), followed by the above ground component (15%) (Figure 5.7). The density of carbon in above ground, below ground and dead biomass is highest in the Sundarban zone followed by the Sal (Table 5.14).

Highlights

- Most of the national carbon stock is in the Village zone (70%, soils to 30cm depth) due to its large spatial extent.
- Carbon density in below ground biomass is 9.6 times higher in the Sundarban zone compared to the national average.
- The Hill zone is highest in soil carbon (up to 30 cm) and litter carbon compared to other zones.
- In the Coastal and the Sundarbans zones soil carbon density in 100 cm depth is more than double the 30 cm depth.

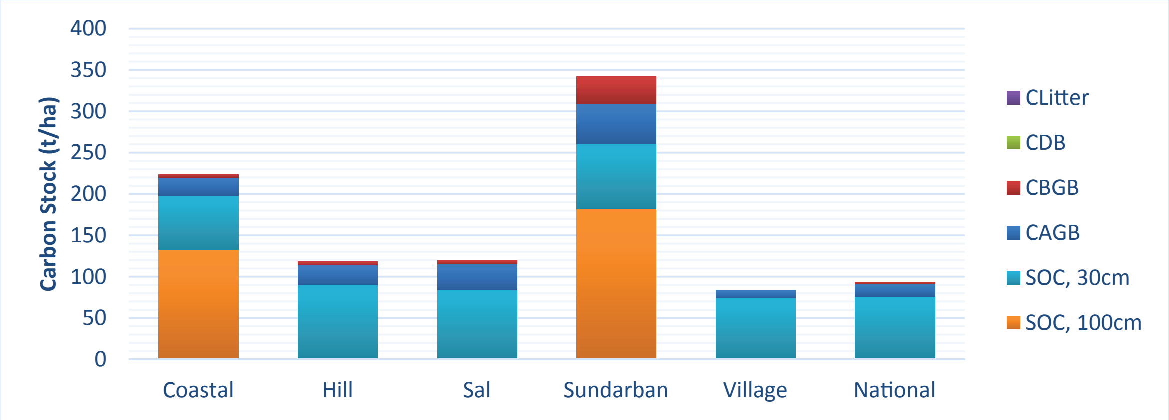


Figure 5.7: Carbon stock densities in the major pools by zone (DB: dead biomass, BGB: belowground biomass, AGB: aboveground biomass, SOC: soil organic carbon for 0-30cm depth soil layer and 30-100 cm depth soil layer). Note that soil data for 30-100cm depth was not collected in the Hill, Sal and Village zones.

Table 5.14: Five carbon pools by zone.

Zone	All Carbon pools															
	CAGB		CBGB		CDB		CLitter		SOC, 30cm[1]		SOC, 100cm[2]		All pools (incluing SOC 100 cm)[1]	All pools (including SOC 30 cm)[1]	Total Stock (including SOC 100 cm)[1]	Total Stock (including SOC 30 cm)[1]
	t/ha	SE (±%)	t/ha	SE (±%)	t/ha	SE (±%)	t/ha	SE (±%)	t/ha	SE (±%)	t/ha	SE (±%)	t/ha	t/ha	Million t	Million t
Coastal	21.79	20.26	4.15	19.89	1.21	46.78	0.05	37.2	65.77	7.20	132.48	9.15	225.46	92.98	115.01	47.43
Hill	24.03	14.48	4.65	14.46	1.53	27.4	0.28	10.31	89.97	3.50				120.46	199.83	199.83
Sal	31.36	17.23	5.09	16.84	0.44	23.45	0.16	24.92	84.05	6.38				121.10	63.23	63.23
Sundarban	49.28	8.10	33.03	7.14	2.55	18.10	0.16	16.09	78.68	3.87	181.52	4.33	345.21	163.70	139.28	66.04
Village	10.47	10.18	1.99	10.61	0.15	14.69	0.03	19.15	74.18	3.03				86.82	899.02	899.02
National	14.55	6.68	3.45	5.82	0.44	13.59	0.07	8.23	76.33	2.35	154.13		248.97	94.84	1,416.37	1,275.55

[1] Soil organic carbon (SOC) was determined by LOI without removing inorganic carbonates which typically results in higher values than other methods. Samples for 100 cm soil layer were collected from the Sundarbans and Coastal zone only. Carbon density and total carbon stock is calculated for both 30cm and 100cm depths. The 30cm depth estimates may be used for most consistent comparisons among zones and for the national level estimate.

5.4.2 Carbon Pools by Administrative Division

Description

Administrative divisions are often used for policy and planning purposes. The five carbon pools were summarized by administrative units for the purpose that planners may understand the status of carbon stocks in their divisions and use the information as a baseline for climate change policies. Overall, the carbon densities are higher where there are more forests. For example, in Chittagong and Khulna where the Mangrove and Hill Forest is common (Table 5.15).

Highlights

- The Khulna division has the highest carbon stocks by density, and Rangpur has the lowest.
- The total carbon stocks are highest in Chittagong and Khulna divisions which together have 38% of the total carbon stock.

Table 5.15: Five carbon pools by administrative division.

Division	Carbon density by pool (t/ha)						
	CAGB	CBGB	CDB	CLitter	SOC, 30 cm[1]	Total	
						Mean	Total (million t)
Barisal	24.61	4.62	0.72	0.06	69.83	99.85	89.91
Chittagong	20.46	3.93	1.03	0.18	79.37	104.97	284.05
Dhaka	13.97	2.51	0.21	0.06	73.57	90.33	152.86
Khulna	18.84	8.47	0.61	0.06	79.80	107.77	203.82
Mymensingh	10.12	1.88	0.06	0.02	73.50	85.57	81.83
Rajshahi	11.20	1.94	0.14	0.03	66.90	80.21	137.98
Rangpur	8.36	1.70	0.14	0.02	65.29	75.52	160.18
Sylhet	6.83	1.24	0.21	0.03	101.79	110.12	164.91

[1] Soil organic carbon (SOC) was determined by LOI without removing inorganic carbonates which typically results in higher values than other methods. Samples for 100 cm soil layer were collected from the Sundarbans and Coastal zone only. The 30cm depth estimates may be used for most consistent comparisons among divisions.

5.4.3 Total Carbon by Zone and Land Cover Class

Description

Most of the carbon stock is contained in the top 30 cm of the soil (80%), followed by the above ground component (15%) (Figure 5.7). The density of carbon in above ground, below ground and dead biomass is highest in the Sundarban zone followed by the Sal (Table 5.16).

Highlights

- Most of the national carbon stock is in the Village zone (70%, soils to 30cm depth) due to its large spatial extent.
- Carbon density in below ground biomass is 9.6 times higher in the Sundarban zone compared to the national average.
- The Hill zone is highest in soil carbon (up to 30 cm) and litter carbon compared to other zones.
- In the Coastal and the Sundarbans zones soil carbon density in 100 cm depth is more than double the 30 cm depth.

Royal Bengal Tiger, The Sundarban *©FD*

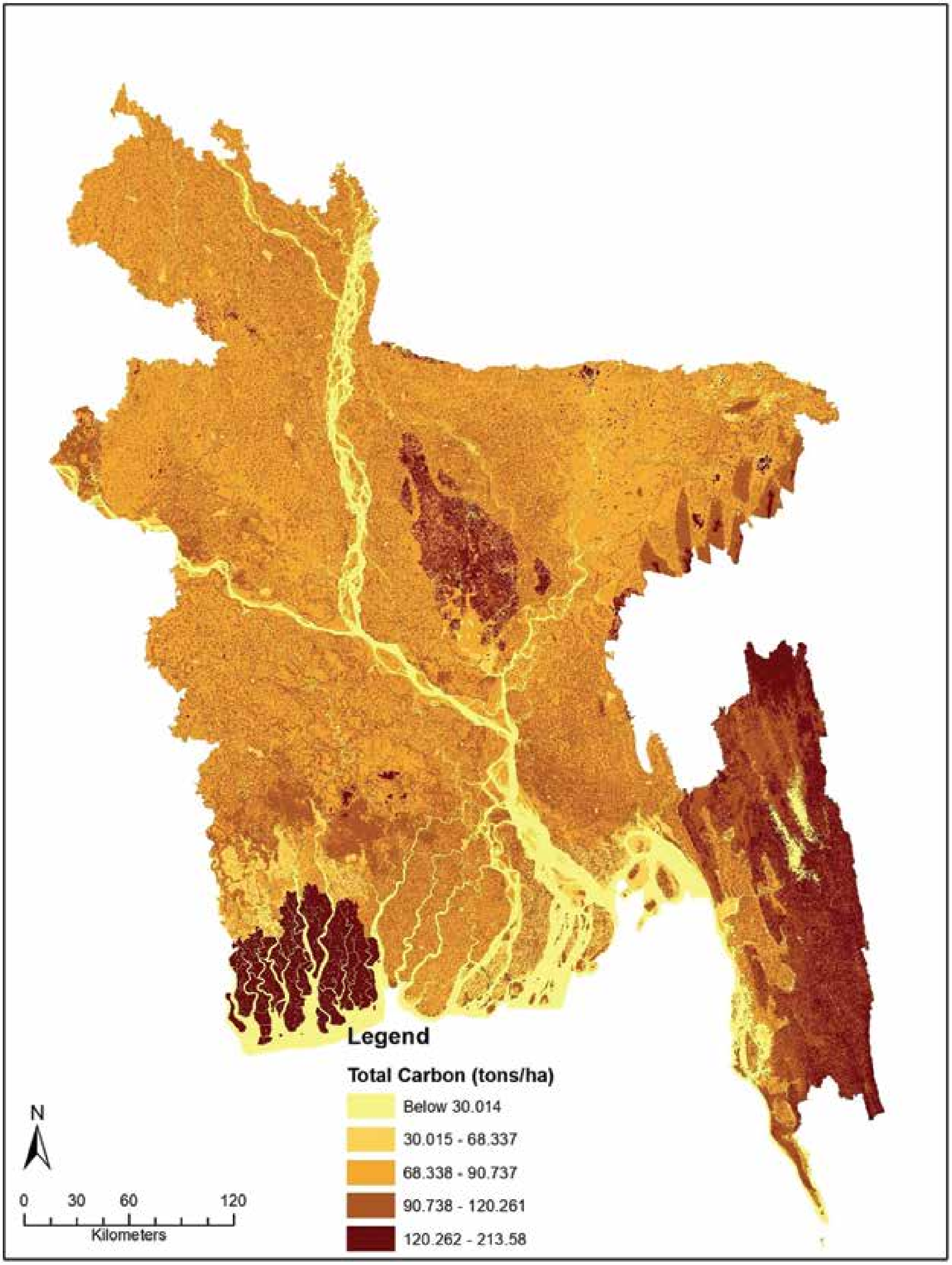


Figure 5.8: Spatial distribution of all five carbon pools (SOC to 30cm).

Table 5.16: Total of all five carbon pools by land cover class and zone (SOC to 30cm).

Land Cover Classes	Total carbon (t/ha)	Total carbon (million t)	Distribution of carbon in zones (t/ha)				
			Coastal	Hill	Sal	Sundarban	Village
Forest							
Bamboo Forest	176.62	1.37		176.90			
Mangrove Forest	163.66	65.99				162.25	
Hill Forest	144.42	123.08		144.65			107.45
Rubber Plantation	139.03	8.09		100.93	213.58		
Plain Land Forest (Sal Forest)	125.47	5.69			126.55		109.80
Mangrove Plantation	121.08	23.52	120.06				
Forest Plantation	116.03	15.12		120.26	111.37		0.00
Shrubs with scattered trees	112.45	`31.21	105.49	112.50	7.91		0.00
Total Forest	**145.47**	**274.07**	**111.54**	**129.08**	**117.99**	**162.18**	**26.16**
Other Land (TOF)							
Perennial Beels/Haors	122.23	4.10			4.37		124.63
Shifting Cultivation	114.60	1.78		114.87			
Fresh Water Aquaculture	104.60	12.22	56.03				104.98
Orchards and Other Plantations (Trees)	103.72	26.00		104.89	171.57		93.50
Rural Settlement	102.50	211.66	104.09	108.78	140.60		100.22
Riverbanks	101.29	0.63		94.55	25.26		125.07
Orchards and Other Plantations (Shrub)	97.34	11.84		94.31			43.22
Ponds	90.27	0.45			67.34		70.96
Single Crop	82.94	389.92	68.34	97.29	110.61		82.36
Multiple Crop	79.95	322.05	54.39	74.58	90.63		80.08
Herb Dominated Area	73.01	4.89	77.71		109.98		66.99
Built-Up Non-Linear	63.64	7.50	83.43		76.69		60.46
Brackish Water Aquaculture	62.97	2.72					63.01
Mud Flats or Intertidal Area	54.70	1.42	54.03				0
Brickfield	49.96	1.11			53.18		49.54
Dump Sites/ Extraction Sites	35.74	0.59					35.74
Swamp Reed Land	15.06	0.15					15.06
Sand	14.64	2.44					14.64
Total Other Land (TOF)	**77.80**	**1001.47**	**33.84**	**83.39**	**110.38**	**0.00**	**81.03**

5.4.5 Soil Carbon by Zone and Land Cover Class

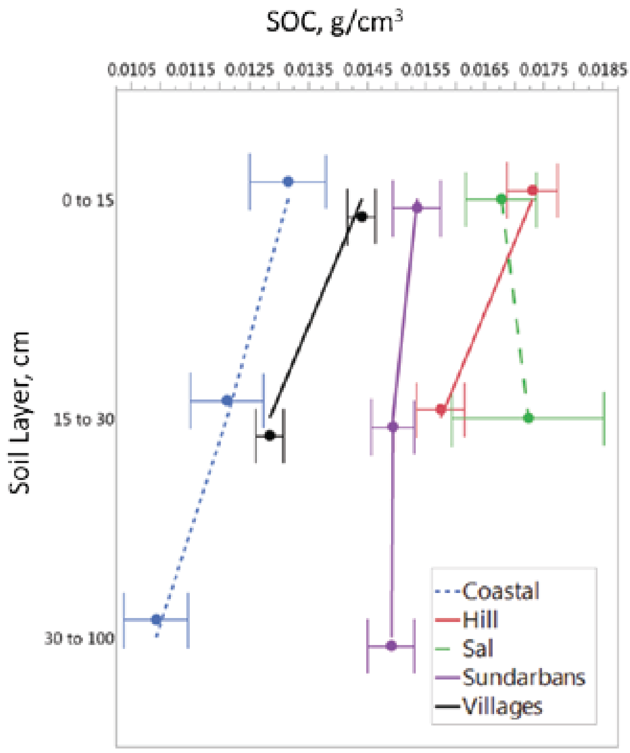


Figure 5.9: Soil carbon (g/cm³) by depth and by zone. Error bars indicate the stand error of the estimate.

Description

SOC density varies by zone and soil layer. The Hill zone shows highest SOC density up to 30cm depth whereas the lowest SOC density is in the Coastal zone (Table 5.17; Figure 5.10).

Highlights

- The decrease of SOC from 0-15cm to 15-30 cm is highest in the Hill, Village, and Coastal zones (Figure 5.9).
- SOC in the Sundarban zone is about 49 t/ha higher than the Coastal zone in the 30 to 100 cm.
- Among Forest land cover classes, Bamboo Forest shows the highest SOC density (Table 5.18).

Table 5.17: Soil carbon by depth and zone.

Zone	SOC density and stock distributed into different soil depth											
	0-15 cm			15-30 cm			0-30 cm			30-100 cm		
	Mean (t/ha)	Total (million t)	SE	Mean (t/ha)	Total (million t)	SE	Mean (t/ha)	Total (million t)	SE	Mean (t/ha)	Total (million t)	SE
Coastal	34.25	17.47	8.41	31.52	16.08	7.72	65.77	33.55	7.20	132.48	67.58	9.15
Hill	47.21	78.31	3.40	42.76	70.93	3.93	89.97	149.24	3.50			
Sal	42.83	22.36	6.74	41.22	21.52	6.94	84.05	43.89	6.38			
Sundarban	39.86	16.08	4.43	38.82	15.66	4.02	78.68	31.74	3.87	181.52	73.24	4.33
Village	39.16	405.48	2.98	35.02	362.69	3.39	74.18	768.17	3.03			
National	40.13	539.70	2.33	36.20	486.87	2.63	76.33	1,026.59	2.35	154.13	140.82	2.43

Soil organic carbon (SOC) was determined by LOI without removing inorganic carbonates which typically results in higher values than other methods. Samples for 100 cm soil layer were collected from the Sundarbans and Coastal zone only.

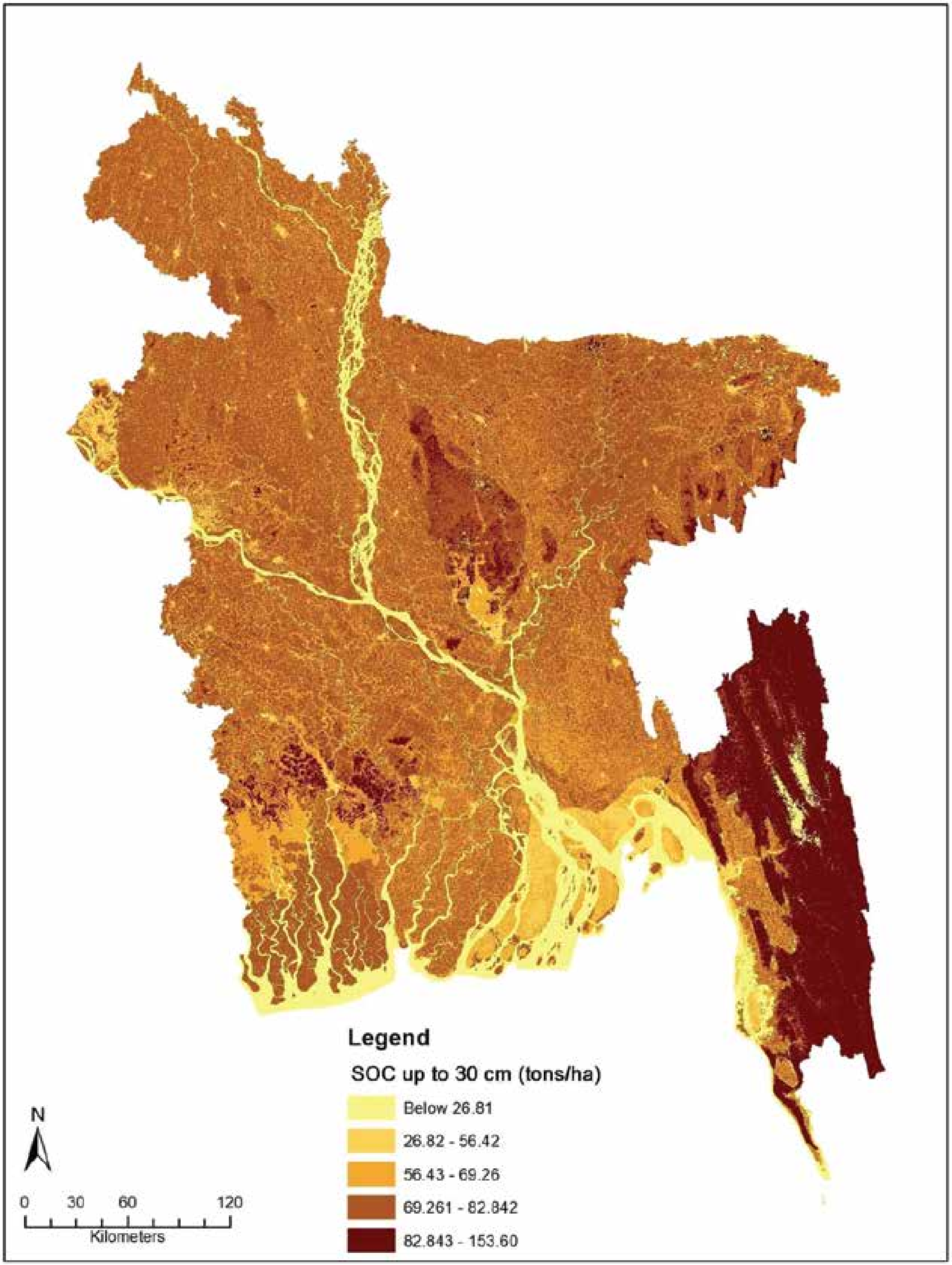


Figure 5.10: Map of the spatial distribution of soil carbon.

Table 5.18: Soil carbon by depth and land cover class.

Land cover class	Number of plots	Distribution of SOC (t/ha) by layer (cm)			SOC to 30cm (t/ha)	Total SOC to 30 cm (million t)
		0-15	15-30	30-100		
Forest						
Bamboo Forest	1	79.04	74.56		153.60	1.26
Shrubs with scattered trees	34	49.23	46.10		95.33	21.45
Hill Forest	214	48.57	43.15		91.72	90.37
Plain Land Forest (Sal Forest)	9	40.53	41.54		82.07	3.86
Rubber Plantation	11	43.15	37.73		80.88	5.20
Forest Plantation	26	42.06	38.62		80.68	11.80
Mangrove Forest	167	39.86	38.82	181.52	78.68	31.74
Mangrove Plantation	35	38.41	35.44	160.00	73.84	15.73
Total Forest	**497**	**46.28**	**42.76**	**43.43**	**89.04**	**181.41**
Other Land (TOF)						
Perennial Beels/Haors	3	66.28	55.96		122.23	4.10
Fresh Water Aquaculture	15	57.24	45.79	79.50	103.02	12.04
Shifting Cultivation	5	53.33	45.43		98.76	1.30
Riverbanks	4	48.33	40.60		88.94	0.33
Orchards and Other Plantations (Shrub)	17	41.54	38.87		80.42	10.19
Single Crop	434	41.67	38.03	123.42	79.71	375.24
Multiple Crop	442	40.20	36.13	99.86	76.34	310.54
Herb Dominated Area	10	38.42	33.50	127.28	71.92	4.83
Ponds	1	40.66	30.30		70.96	0.30
Brackish Water Aquaculture	5	35.94	26.97		62.91	2.72
Rural Settlement	204	32.98	28.97	102.82	61.95	94.45
Orchards and Other Plantations (Trees)	34	32.68	27.87		60.56	17.44
Mud Flats or Intertidal Area	5	27.32	26.66	121.97	53.99	1.41
Brickfield	3	27.60	21.41		49.02	1.09
Built-Up Non-Linear	15	26.22	22.16		48.38	6.22
Dump Sites/ Extraction Sites	1	15.39	20.35		35.74	0.59
Sand	13	7.69	6.65		14.35	2.40
Total Other Land (TOF)	**1211**	**34.20**	**30.56**	**41.49**	**64.77**	**845.19**

Soil organic carbon (SOC) was determined by LOI without removing inorganic carbonates which typically results in higher values than other methods. Samples for 30-100 cm soil layer were collected from the Sundarbans and Coastal zones only.

5.4.6 Soil Properties by Land Cover Class

Description

Soil carbon was not the only soil property measured in the BFI. Texture, pH, and Salinity (EC, electric conductivity) were also measured and can give an indication of the quality of soils for certain land cover classes. Soil texture sampled were collected for all soils and depths. In contrast, pH and EC were only measured in the Coastal and Sundarban zones (Table 5.19).

Highlights

- Sandy soils occur in land cover classes typically occurring in hilly areas such as Bamboo Forest, Hill Forest, and Shifting Cultivation.
- EC is noticeably higher, i.e. more saline, in the Mangrove forest compared to the Mangrove Plantation.
- Shrubs with scattered trees and Salt Pans have soils with the lowest pH, i.e. most acidic.

River Kingfisher, The Sundarban
©*Falgoonee Kumar Mondal*

Table 5.19: Soil properties by depth and land cover class.

Land Cover Classes	Texture (%)			pH in different soil depth (cm)			Salinity (mS/cm in different depth (cm)		
	sand	silt	clay	0-15	15-30	30-100	0-15	15-30	30-100
Forest									
Mangrove Forest	2.28	50.67	47.05	7.43	7.48	7.34	2.82	2.58	2.90
Mangrove Plantation	3.90	56.96	39.14	7.47	7.62	7.73	1.88	1.67	1.63
Bamboo Forest	42.93	19.63	37.45						
Plain Land Forest (Sal Forest)	29.58	40.96	29.47						
Shrubs with scattered trees	51.37	23.44	25.19						
Forest Plantation	48.89	27.46	23.64						
Rubber Plantation	52.38	25.43	22.20						
Hill Forest	58.96	20.01	21.03						
Total Forest	**41.90**	**29.34**	**28.72**	**7.40**	**7.46**	**7.30**	**2.68**	**2.44**	**2.72**
Other Land (TOF)									
Brackish Water Aquaculture	6.65	52.19	41.16						
Fresh Water Aquaculture	27.31	35.76	36.93	8.10	8.18	8.18	0.87	0.66	0.53
Herb Dominated Area	34.53	33.10	32.36	7.18	7.31	7.37	2.42	1.44	1.24
Single Crop	37.38	35.27	27.35	7.49	7.54	7.70	0.34	0.37	0.41
Perennial Beels/Haors	62.46	10.43	27.11						
Ponds	52.49	20.69	26.83						
Multiple Crop	40.04	35.12	24.84	7.34	7.48	7.59	0.29	0.25	0.28
Orchards and Other Plantations (Shrub)	55.77	20.23	24.01						
Shifting Cultivation	59.99	16.23	23.79						
Rural Settlement	36.24	40.39	23.37	7.24	7.54	7.63	0.56	0.46	0.39
Mud Flats or Intertidal Area	5.22	72.68	22.11	7.56	7.64	7.77	1.10	0.95	0.78
Orchards and Other Plantations (Trees)	42.92	35.67	21.42						
Riverbanks	45.46	34.93	19.61						
Brickfield	56.1	25.73	18.18						
Built-Up Non-Linear	59.88	25.56	14.56	7.37	7.49		0.57	0.27	
Sand	72.99	20.02	7.00						
Dump Sites/ Extraction Sites	96.43	1.63	1.95						
Total Other Land (TOF)	**38.19**	**36.44**	**25.37**	**7.30**	**7.44**	**7.54**	**0.54**	**0.48**	**0.45**

Samples for pH, salinity, and 30-100 cm soil layer were collected from the Sundarbans and Coastal zones only.

Section 6:

Criteria 4 - Management and Ownership

A landscape of hill forest ©Falgoonee Kumar Mondal

Criteria 4

Forest Management and Ownership

Section Highlights

- In 23% of the land in Bangladesh, some form of management is observed (e.g. Homestead Forestry, Orchard, Tea garden, etc.).
- Several types of plantation management (e.g. coastal, rubber, strip and woodlot plantations) account for 50% of managed areas.
- Aboveground carbon is about two or three times higher on FD land compared to other ownership types.
- Private lands are the major supplier of tree and forest products in the form of energy, materials, and nutrition according to respondents of the socio-economic survey.

Introduction

Tree and forest resources are better understood when knowing who owns them and how they are managed. Both the biophysical and socio-economic surveys provide estimates about the relative types of management and ownership, and the types of services they provide. This criterion looks at the extent and types of forest management. It answers questions such as what is the area of management activities, and what is the status of ownership of tree and forest land? In general, Bangladesh is highly managed and diversified in the types of management. Monoculture plantations occur throughout the country, but the locations and types of plantations (tea gardens, woodlots, strip plantations, orchards, etc.) vary substantially.

Methods

The managed forest area refers to any vegetated land feature which field teams observed signs of human management. Thus, it does not directly correspond to forest land areas managed by the FD. Vegetated land feature areas with specific management types were summed and then divided by the total sampled area of the population of interest (Hossain Anik *et al*. 2019). Ownership of the land feature was noted by field teams and the area was estimated the same way as management type. Thus, the areas of management and ownership type are a sample-based estimates, meaning no maps were used. Volume, biomass, and carbon were estimated the same as outlined in Section 5.

The land from which tree and forest products are collected by ownership type was determined by asking respondents of the socio-economic survey *"What are the tree and forest products collected by your household?"* and *"What is the ownership of the land from where the product was collected?"* The products collected were grouped into categories of Materials (e.g. bamboo, timber), Energy (e.g. fuelwood, leaves), or Nutrition (e.g. fruits). The results were summarized by the percent of households responding they collected from the specified ownership type, regardless of the quantity of the product collected.

Deer, The Sundarban *©Zaheer Iqbal*

6.1

Tree and Forest Management Types

Description

At least 23.23% of the land has some type of tree and forest management as observed by field observations. General type plantation is the most common management type observed, covering 5.63% of the total country area (Table 6.1). This management types describes tree covered areas that include planted fruit, timber or fuelwood producing species.

Other plantation forestry e.g. woodlot, coastal, rubber and strip) are important management types, accounting for 5.54% of total country area (Table 6.1). Woodlot plantations are plantations under social forestry programmes for timber and fuelwood usually in small patches. Coastal plantations are in coastal areas and newly accreted land with mangrove species and includes dyke and mound plantations. Strip Plantations are narrow timber plantation in marginal land (for example along road sides or river embankments).

Agro-forestry systems are land use management in which trees or shrubs are grown around or among crops or pastureland. Village Common Forests are community managed natural forests or Mouja Ban in the CHT. Other definitions can be found in the BFI manual (FD 2016).

In terms of aboveground volume, biomass and carbon stocks (m^3/ha), Coastal Plantation is the highest and Agro-forestry system is the lowest (Table 6.2). Although Bamboo groves ranks 7th in terms of area and 14th in terms of volume density, it ranks 10th in terms of AGB and CAGB. Note that the Bamboo grove management type is different from the Bamboo Forest, which is a land cover class that only occurs in the Hill zone (Section 3.1 and 5.1.5).

Highlights

- About 23.23% of the land in Bangladesh has some kind of tree and forest management.
- Homestead gardens and orchards both have high amounts of aboveground biomass and carbon

- Coastal plantations make up 83% of the managed area in the Coastal zone.
- Agro-forestry systems make up 12% of the managed forest area and are located mostly in the Village zone. Yet, volume, biomass and carbon stocks (m^3/ha) are lower in this type compared to other types.

Table 6.1: Percentage and area of management types ranked by area.

Management Type	Percentage of country area	Total managed area (ha) [1]
Plantation (general)	5.63	757,005.4
Woodlot plantation	3.38	453,983.4
Agro-forestry system	2.90	390,428.9
Coastal plantation	1.04	140,116.3
Tea garden	0.60	80,659.9
Rubber Plantation	0.58	78,013.9
Bamboo groves	0.55	73,764.5
Strip Plantation	0.54	72,197.3
Orchard	0.49	65,478.6
Village Common Forests	0.21	27,666.0
Jhum	0.07	9,104.0
Homestead Forest	0.06	8,023.9
Urban parkland	0.04	5,019.9
Other	7.16	962,390.3
None observed	76.78	1,0326,257.0

[1]Sample-based estimate based on observations from field teams.

[2]Urban parkland only occurred in one plot in Sreemangal of the Hill zone.

[3]None observed refers to the field team not finding evidence for any type of specific forest management on the plot

Table 6.2: Volume, aboveground biomass (AGB), and carbon in aboveground biomass (CAGB) by management type in m^3/ha and ranked by volume.

Management Type	Volume (m^3/ha)	AGB (t/ha)	CAGB (t/ha)
Agro-forestry system	14.88	14.18	7.13
Bamboo groves	7.06	27.34	14.52
Coastal plantation	89.60	75.56	37.71
Homestead Forest	73.81	52.34	25.28
Jhum	35.12	35.11	17.45
None observed	23.08	23.76	12.01
Orchard	45.09	51.21	25.86
Other	82.89	79.16	40.05
Plantation (general)	62.13	63.69	32.49
Rubber Plantation	38.01	70.92	36.64
Strip Plantation	27.66	20.83	10.40
Tea garden	29.79	23.07	11.15
Urban parkland	33.06	26.50	12.74
Village Common Forests	44.33	51.03	24.92
Woodlot plantation	31.90	32.61	16.35

6.2

Trees and Forest by Ownership Class

Description

The biophysical inventory plots are a sample of the land area of the country. It is therefore possible to estimate the area of ownership type based on the proportion of land features which belong to specific ownerships. Government (other) refers to land owned by governments, or by government-owned institutions or corporations other than the Forest Department (e.g. Railways, Water Development Board, Roads and Highways). Un-classed State Forest (USF) was also considered under Government (other). Unknown and Other ownership was sometimes recorded for pond, river banks and other cases where ownership was unclear. In addition to area, the aboveground volume, biomass and carbon stocks are given.

Most of the sampled area was owned privately (Table 6.3). Aboveground volume, biomass and carbon stocks are highest on lands owned by the FD. Carbon in AGB on FD land, for example, are about two or three times higher than any other ownership type.

Highlights

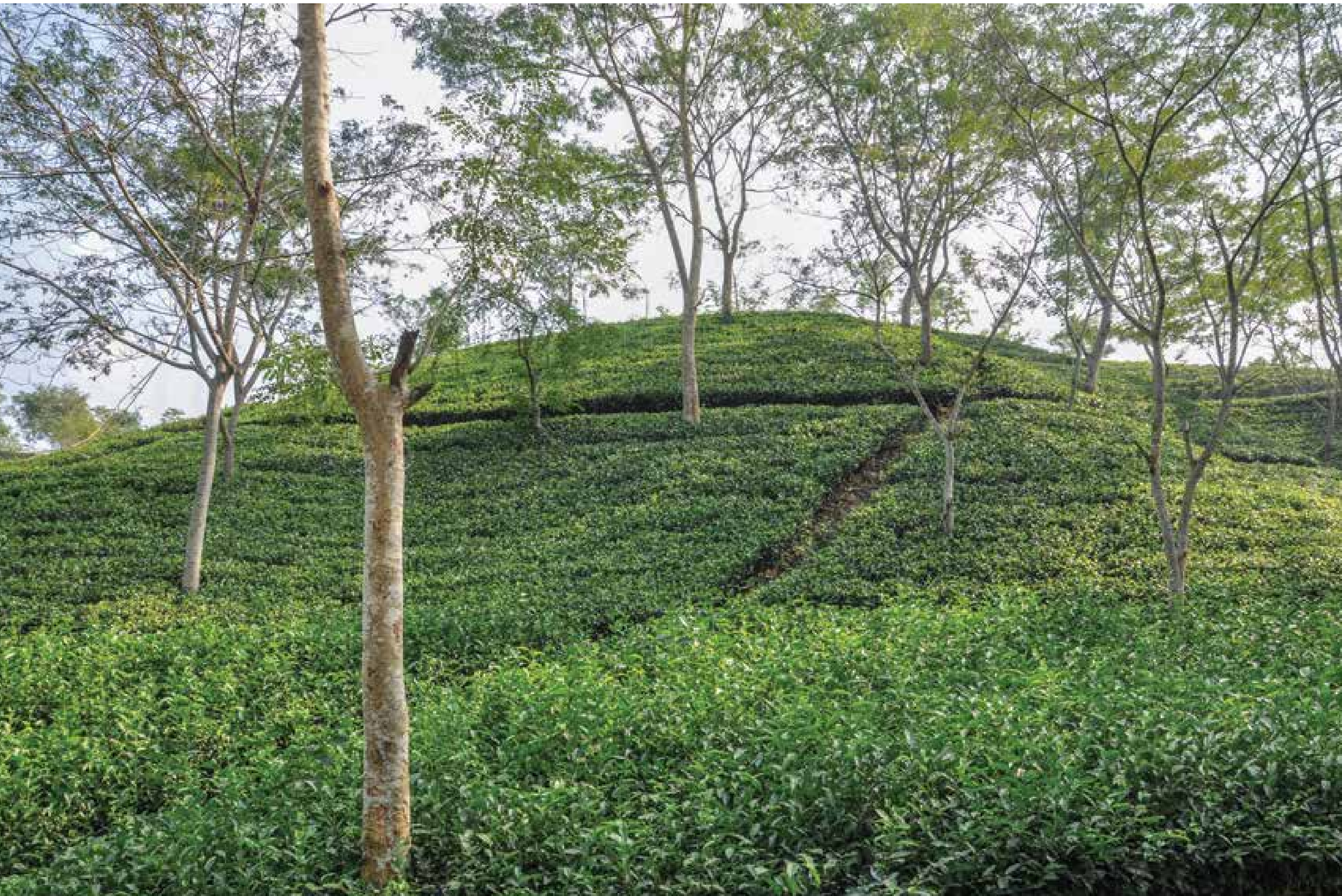
- About 23.23% of the land in Bangladesh has some kind of tree and forest management.
- Homestead gardens and orchards both have high amounts of aboveground biomass and carbon
- Coastal plantations make up 83% of the managed area in the Coastal zone.
- Agro-forestry systems make up 12% of the managed forest area and are located mostly in the Village zone. Yet, volume, biomass and carbon stocks (m^3/ha) are lower in this type compared to other types.

Table 6.3: National estimates of volume, biomass and area under different ownership classes.

Ownership class[1]	Total area (ha)[1]	% of country area	Volume (m^3/ha)	AGB (t/ha)	CAGB (t/ha)
Forest Department	1,264,319.0	9.40	79.43	75.62	37.94
Government (other)	1,034,888.0	7.69	24.78	28.57	14.37
Other[2]	50,501.6	0.38	59.12	95.17	48.91
Private	10,857,811.8	80.73	22.53	22.69	11.51
Unknown	242,588.8	1.80	42.29	44.47	21.87

[1]Ownership class was determined by field teams, often by asking local landowners. The area is a sample-based estimate applied to the total country areas.
[2]The other category mainly includes the marginal areas of Rivers, Khals, and Lakes.

Tea garden, Sylhet *©Zaheer Iqbal*



6.3

Tree and Forest Product Collection by Ownership Type

Description

Most households collected primary forest products from private lands than any other ownership. The highest use of these products is for providing energy, followed by materials and then nutrition (Table 6.4). Comparatively little forest products are collected from government lands.

Highlights

- At the national level, 18.6% of households on average collect tree and forest products from privately owned land.
- Energy, which is mostly fuelwood and leaves, is commonly collected on privately owned lands.

Table 6.4: Percentage of households (of the total households surveyed) that collected tree and forest products by land ownership type and by the product category.

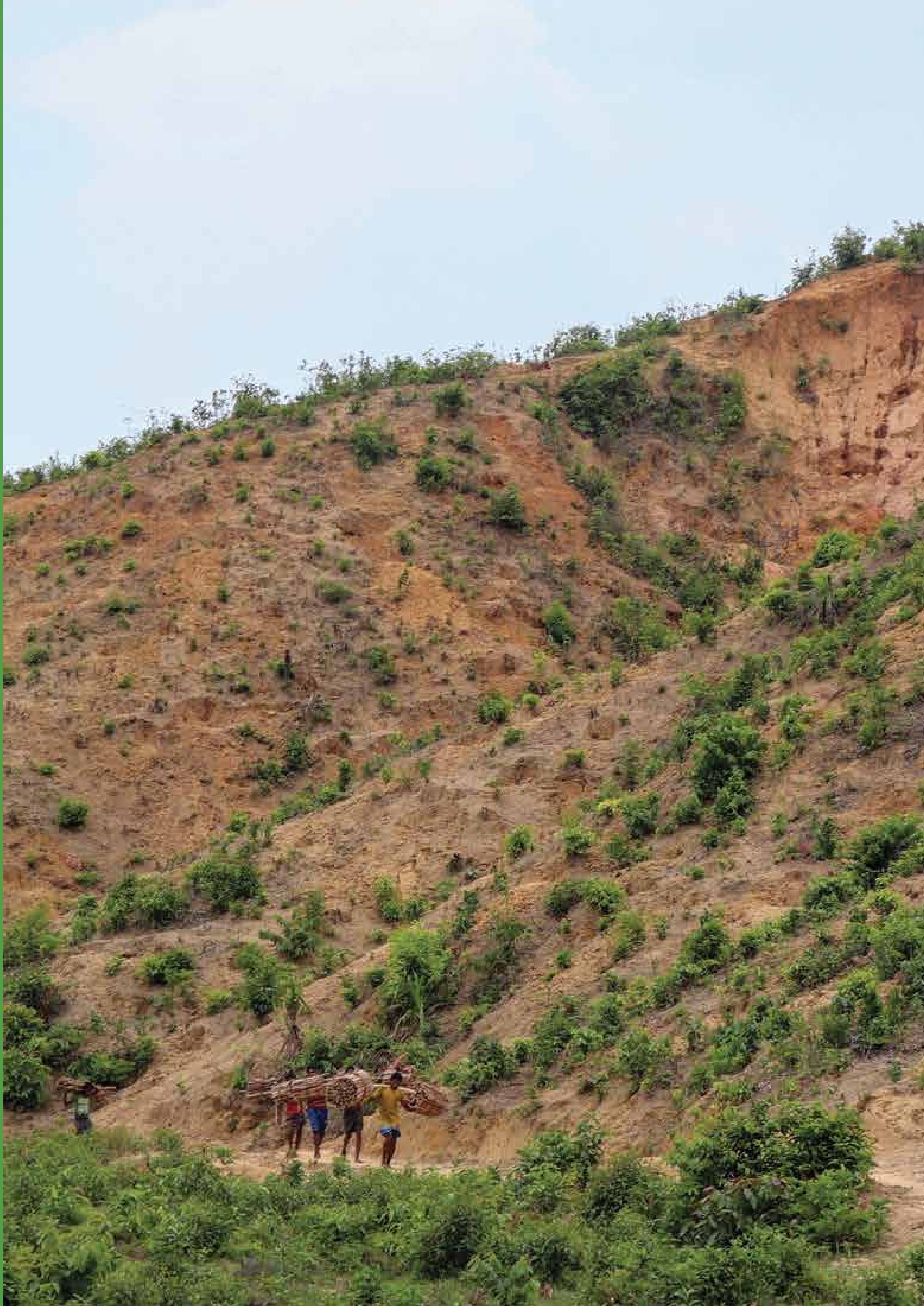
Tree and forest product category1	Private (%)	Forest Department (%)	Other Government (%)	Community institutions (%)	Other / Unknown (%)
Material	8.0	0.3	0.0	0.2	0.0
Energy	41.2	2.1	0.2	0.9	0.3
Nutrition	6.6	1.2	0.1	0.0	0.2
Avg	18.6	1.2	0.1	0.4	0.2

[1]Material (e.g. bamboo, timber), Energy (e.g. fuelwood, leaves), or Nutrition (e.g. fruits).

Costal plantation of Moheshkhali ©*Md. Fazlay Arafat*

Section 7:

Criteria 5 - Tree and Forest Disturbances



Forest resource destruction in hill *©Mateiu Henry*

Criteria 5

Tree and Forest Disturbances

Section Highlights

- Disturbance is observed in 32% of the country at the time of the biophysical survey. Waterlogging, flooding and pests were the most common disturbances nationally.
- Cyclone (78%) and Infrastructure development (56%) are the most common disturbances observed by respondents of the socio-economic survey. In the Coastal zone, cyclone affects 57.7% of the land and was observed by 98% of the respondents.
- According to respondent opinions, the main driver of tree cover gain in the Coastal zone is increasing coastal plantations. The main drivers of tree cover loss in the Hill and Sal zones are human-caused such as urbanization and management of forests (e.g. overharvesting, perhaps by locals, and not planting new trees).

Introduction

Bangladesh is known for the impacts of extreme weather and other natural disasters on its general population. Human disturbances are also significant and often interact with natural disturbances. Data from both the biophysical and socio-economic surveys indicate the relative extent and impact of disturbances by either land area or number of households, respectively. This criterion describes various disturbances that occur and their effect on the health of trees and forests. The negative impacts of such disturbances may contribute to a loss of benefits. This indicator answers questions such as - what is the severity of natural and anthropogenic disturbances in each zone?

Methods

Both the biophysical and socio-economic survey each provide information on tree and forest disturbances. The occurrence of natural and human made disturbances on BFI plots is observed and recorded in the biophysical inventory. The area and percent of disturbance is then expanded by zone area (Akther *et al.* 2019). See Appendix 2.1 for details about which classes were aggregated to Forest and Other Land (TOF).

Households interviewed during the socio-economic survey were asked: *"what types of disturbances have occurred in your union in the past 10 years?"* The data were then summarized by type and zone. The total percent observance in the country is the weighted average.

Tree cover change results from Section 3.3 were used to determine increases and decreases in tree cover by zone. The drivers of tree cover change were identified by asking socio-economic survey respondents *"Have there been any changes in the area of tree cover on your land in the past ten years?"*, and if so, *"What are the reasons for increasing/decreasing tree cover?"* There was no pre-defined list of answers for the respondents to choose from, so open answers were later grouped into common responses. Next, the responses were summarized by zone and presented as ranked lists of the reasons for increasing or decreasing tree cover. Only the five most common reasons within the zones are shown here.

Land slide in Rangamati *©Shovik Chakma*

7.1

Disturbance Area and Disturbances Most Cited by Households

Description

Disturbances were recorded two ways in the BFI. In the biophysical inventory, field team recorded observations of one or more disturbance types on the plots. In the socio-economic survey, households were asked: "*what types of disturbances have occurred in your union in the past 10 years?*"

Overall, three times more land area is disturbed by natural causes than human-made (Table 7.1). Similarly, respondents generally noted more natural disturbance than human caused. There were notable exceptions, however. Over grazing and water pollution were major disturbances affecting land area (a combined total of 1,307,702 ha), and infrastructure development was noted by more than half of the respondents nationally.

In terms of affected land area within zones, the Coastal zone is most affected by cyclone (57.7% of the zone area), the Hill zone by erosion (19.4%), the Sal zone by leaf collection (6.4%), the Sundarban zone by siltation (22.2%), and the Village zone by waterlogging (12.5%).

Highlights

- Cyclone, Flooding, Waterlogging, and Pests are among the top five natural disturbances observed in both the biophysical and socio-economic surveys.
- The largest disturbances to TOF are Waterlogging and Pests/Insects/Fungus (11.0% and 9.1% of the TOF area, respectively).
- Fire is a relatively minor disturbance, but occurred more commonly in the Sal and Hill zones (4.5% and 4.7% of the zone areas, respectively)

Table 7.1: Disturbance expressed by: 1) land area estimates from the biophysical inventory, and 3) the percentage of householdsobserving disturbance in their union.

Disturbance type	Biophysical - Area Estimates[1]								Socio-economic - % Responses					
	% of country area	Forest (1000 ha)	TOF (1000 ha)	CZ (1000 ha)	HZ (1000 ha)	SZ (1000 ha)	SuZ[2] (1000 ha)	VZ (1000 ha)	Nat (%)	CZ (%)	HZ (%)	SZ (%)	SuZ_P[2] (%)	VZ (%)
	Natural disturbances								Natural disturbances					
Waterlogging	9.8	40,801	1,277,754	88,691	27,265	1,708	67,639	1,296,413	28	39	4	4	56	36
Flooding	7.1	73,447	950,717	218,552	12,170	3,816	4,873	725,206	52	85	28	0	94	54
Pests/Insect/Fungus	7.1	26,721	1,048,887	29,962	5,873	0	0	1,177,149	30	15	25	0	73	38
Cyclone / tidal surges	6.8	110,377	822,360	294,481	4,555	0	28,828	468,395	78	98	91	22	99	82
Landslide / erosion	6.2	302,781	316,180	58,269	321,953	23,293	2,436	165,504	23	37	26	1	45	8
Siltation	4.4	106,457	453,819	27,735	5,598	0	89,568	472,432	2	0	0	0	3	8
Drought	2.2	20,981	304,988	706	943	22,658	0	332,112	3	1	0	1	8	2
Storm damage	1.5	44,070	144,460	56,450	4,555	0	29,238	61,652	28	0	1	0	88	51
Others (invasive species, salinity, climate change)	0.7	12,746	84,592	9,464	9,109	0	0	85,568	17	44	4	1	73	11

			Human-caused disturbances						Human-caused disturbances					
Over grazing	5.3	37,304	756,202	53,100	19,589	10,772		758,358	1	0	2	0	1	0
Water pollution	4.4	8,155	667,906	14,196	8,290		1,713	723,606	1	0	0	1	5	0
Encroachment	1.9	93,520	90,987		92,617	17,159	4,873	61,129	19	3	18	2	52	0
Fire	1.7	91,549	68,918	4,732	75,515	24,513		52,478	4	0	15	0	3	9
Leaf collection	1.4	37,052	144,213		15,478	33,569		127,293	22	1	80	0	20	18
Infrastructure development	0.2	0	27,727					31,487	56	41	88	45	40	66
Others (paddy field expansion, shifting cultivation)	0.1	6,778	3,741		9,109				1	0	3	0	0	0
			None observed											
None observed	67.9	993,348	8,467,605	82,212	1,003,073	398,430	219,650	5,573,062	-	-	-	-	-	-

[1]Sample-based estimate based on observation from field teams.
[2]Note that SuZ and SuZ_P cover different areas (section 2.3.1)

7.1

Drivers of Tree Cover Changes

Description

Tree cover change determined from remote sensing is an important indicator of the BFI (Section 3.3). Attributing the changes to specific causes is difficult without a field survey. For this purpose, responses from the socio-economic household survey were used to understand drivers of tree cover change.

There was a large increase in tree cover in the Coastal zone, but only a modest increase in the Village and Sundarban zones (Table 7.2). In the Coastal zone, according to a large number of respondents, this increase is due to increasing tree plantations and related management of coastal forests (Table 7.3). At least some thought that fewer natural disturbances contributed to favorable conditions for tree cover increase (from 9.1% in the Village to 16.9% in the Sundarban periphery).

Net tree cover loss occurred only in the Hill and Sal zones. The absolute loss over the period was highest in the Hill zone (23,807 ha), but by percent it was highest in the Sal zone (13.7%). See also Section 3.3 and (Potapov, Siddiqui *et al.* 2017) for more interpretations about tree cover changes.

Although the Hill and Sal zones are quite different demographically and biophysically, in both places the respondents noted similar reasons for decreasing tree cover. Broadly categorized, they mainly refer to urbanization (infrastructure development and land use change) and management (overharvesting and lack of tree planting) (Table 7.4).

Highlights

- Increasing tree plantations, along with fewer natural disturbances, are possible drivers of increasing tree cover in the Coastal zone.
- Both the Hill and Sal zones are decreasing in tree cover due to mainly human influences according to respondents.
- At least some in the Hill zone noted that Cyclone is a major reason for decreasing tree cover.

Table 7.2: The absolute and percent change in tree cover loss and land cover by zone. Data are from sampled unions only.

Zone	Tree Cover of sampled unions in 2000, ha	Tree Cover of sampled unions in 2014, ha	% Change
Coastal	16,638	18,089	14.60
Hill	232,541	208,734	-10.30
Sal	25,108	21,671	-13.70
Sundarban	10,681	11,891	0.68
Village	9,698	10,088	3.00
National	2,468,716	2,388,622	-3.20

Table 7.3: The five most common reasons mentioned by respondents for increases in tree cover area for those zones where tree cover increased (Table 7.2).

Zone	Reasons for increased tree cover	% respondents
Coastal Zone	More tree plantation	45.31
	Proper management	17.81
	Fewer natural disturbances	10.50
	Profitability	8.53
	Less salinity	4.24
Sundarban periphery	More tree plantation	34.12
	Proper management	24.25
	Fewer natural disturbances	16.89
	Less salinity	8.00
	Profitability	6.44
Village	More tree plantation	41.51
	Proper management	23.33
	Profitability	12.88
	Fewer natural disturbances	9.07
	Reduced extraction plant of species	4.09

Table 7.4: The five most common reasons mentioned by respondents for decreases in tree cover area for those zones where tree cover decreased (Table 7.2).

Zone	Reasons for decreased tree cover	% respondents
Hill Zone	Over harvesting	34.11
	Infrastructure development	19.02
	Land use change	8.17
	No new tree planting	6.62
	Cyclone (e.g. Ayla, Sidor)	5.48
Sal Zone	Tree harvesting	36.26
	No new tree planting	14.46
	Infrastructure development	8.62
	Land use change	8.29
	Population growth	4.47

Section 8:

Criteria 6 - Support for Sustainable Forest Management

Keora plantation in Borguna *©Falgoonee Kumar Mondal*

Section 8

Criteria 6

Support for Sustainable Forest Management

Section Highlights

- Few households receive direct support for sustainable forest management from any organization, reflecting a potential need and opportunity for more training and education.
- The few households who receive support mention trainings and seedling programs. The government and private sectors provides 43% and 58% of this support, respectively.
- A substantial number of households reported buying seedlings, ranging from 30% in the Sal zone to 64% in the Sundarban periphery, which indicates that tree planting is an important activity for many in the country.

Introduction

The benefits of sustainably managing tree and forest resources are recognized by many. The FD and other organizations have programs to promote sustainable forest management which are monitored by the indicators in this section. This criterion describes the overall support of sustainable forest management in terms of implementing programs that improve tree and forest cover. It answers questions such as – which organizations provide support to households for sustainable tree and forest management? And, which areas receive the most seedlings from the FD? Overall the following results suggest that most people in Bangladesh manage their own tree resources without the support of any organization. Thus, there is potential to increase support in the forms of training, education, communication materials, and workshops that share experiences among tree and forest beneficiaries.

Methods

For assessing support to households, respondents of the socio-economic survey were asked: "*What types of support for tree and forest management does your household usually receive?*" and "*Which organization(s) does your household receive support from?*" More than one response was allowed for each case. The percent of each type of support and organization was then reported for those who responded they received support. Similarly, respondents who said they received any seedlings from the FD in the last 12 months were asked: "*How many seedlings did your HH receive?*" Finally, respondents were asked: "*Have you bought any seedlings with your own money?*" and "*How much money was spent for buying tree seedlings?*" The results were then summarized into percentages by zone and follow the procedure outlined in Hossain and Anik *et al.* (2019).

Tree measurement, Sangu forest reserve *@Rajib Mahmud*

8.1

Types of Support Received from Organizations

Description

Knowing the status about who provides sustainable management support and for what is basic information needed for planning policies and activities. About 1.1% of the respondents in the country report receiving some type of support for tree and forest management (Table 8.1). However, this figure rises to 6.9% when considering Hill zone areas with high tree cover and low populations (i.e. Hill_4 strata; results not shown).

Among those who receive support, 55% reported the private sector as the source while 33% reported the government sector. Other sources of support include universities, schools and NGO's. Support is usually in the form of training or providing seedlings. Support on raising nurseries exclusively concerns the Sundarban periphery and the Village zones. Training in processing forest products was reported exclusively in the Hill zone (Table 8.1).

Highlights

- The Hill zone receive the most support from organizations, followed by the Sundarban periphery
- The Coastal, Village and Sal zones receive the lowest support.Most of the support provided is in the form of tree planting and free seedlings (Table 8.1).

Table 8.1: Zone level responses for percent of households who received support from any organization and the type of support they received.

Zone	Any Support (%)	Cash (%)	Free seedlings (%)	Other (%)	Training in forest product collection and processing (%)	Training on raising nursery (%)	Training on tree and forest management (%)	Training on tree planting (%)
Coastal	0.95	0.14	0.76	0.00	0.00	0.00	0.00	0.46
Hill	3.13	0.00	2.36	0.00	0.11	0.00	0.24	1.72
Sal	1.28	0.00	0.35	0.23	0.00	0.00	0.05	0.65
Sundarban periphery	2.28	0.21	1.75	0.00	0.00	0.32	0.12	0.83
Village	1.03	0.00	0.00	0.20	0.00	0.04	0.04	0.34
National	1.13	0.01	0.43	0.19	0.02	0.04	0.08	0.63

8.2

Households Receiving Seedling Support from BFD

Description

Another way to support sustainable forest management is through seedling distribution. The FD About 0.15% of households, or approximately 48,000 total households, in the country received seedlings from the FD over a 12 months period from 2017 to 2018. A greater proportion of households received seedings in the Coastal zone (Table 8.2). In the case that seedlings were received, the average number received per household ranged from 5 to 32. Although these figures are modest, they do indicate some activity for promoting tree planting and potential for growing this type of support in the future.

Highlights

- Seedling distribution by the FD was limited over a one-year period and not distributed equally across the zones.
- Seedling distribution is much lower in the Sundarban periphery and Village zones.
- Of those who did receive seedlings from FD, the average number received is 13 per household.

Table 8.2: Zone level responses of the average number of seedlings received by households who received seedling from the FD in the last 12 months.

Zone	% HH receiving seedling	Total no. of HH	Average no. of seedlings per HH[1]
Coastal	0.87	8,155	9.73
Hill	0.55	4,827	18.40
Sal	0.14	5,722	31.50
Sundarban periphery	0.11	403	5.00
Village	0.11	29,558	5.50
National	0.15	48,665	12.68

[1]The estimated average for households who reported receiving seedlings from the FD, i.e. it does not include all households surveyed.

8.3

Seedlings Purchased by Households

Description

The percent households buying seedlings and the number they purchase indicates the tree planting activities of communities. Over half of the population in Coastal and Sundarban periphery zones reported purchasing tree seedlings using their own financial resources, but they were among the lowest in average money spent (Table 8.3). National level results reflect heavily the results of the Village zone, where 45% spent their own financial resources on seedlings.

Highlights

- The percent who spent their own financial resources ranges from 27.4% (Sal) to 66.8% (Sundarban periphery).
- For those who spend their own financial resources on seedlings, the highest average amount spent is in the Village zone, which may reflect the lower number of naturally growing trees in these areas.
- A lower proportion of people in the Sal zone spend their own financial resources which may reflect higher urbanization and less direct dependence on tree resources in the areas. Nonetheless, almost a third of households in the Sal zone still purchase their own seedlings.

Table 8.3: Zone level responses for number of households purchasing seedlings and the average amount spent per year using their own financial resources.

Zone	% who spent own financial resources	No. of HHs who spent own financial resources	Average money spent (BDT/HH/yr)[1]
Coastal	54.2	509,696	1,542
Hill	48.0	418,166	2,093
Sal	27.4	1,086,056	1,378
Sundarban periphery	66.8	256,014	1,202
Village	44.9	12,075,438	905
National	43.4	14,345,371	1,015

[1]Average spent was based on only those households who reported spending their own financial resources for seedlings.

A portion of Hill forest, Sajek ©Falgoonee Kumar Mondal

Section 9:

Criteria 7 - Tree and Forest Services and Livelihoods

Tree and forest services in dailylife *©Falgoonee Kumar Mondal*

Section 9

Criteria 7

Tree and Forest Services and Livelihoods

Section Highlights

- Every household surveyed benefits from at least one tree and forest related service according to the survey.
- 64% of the total population is involved with primary tree and forest product collection, with almost equal participation of both male and female.
- About three quarters of the major primary products are supplied from TOF which cover 87.2% of the total country area (see Section 3.1).
- Tree and forests are an important source of employment for women. Around 65% of the country's total female population are involved with collecting primary tree and forest products.
- The total value of the primary tree and forest products collected is 3.11% of the 2017-18's national Gross Domestic Product (GDP) measured in current price.
- Trees and forests contribute 1.29% of the 2017-18's national Gross National Income (GNI) measured in current market price.
- Nationally fruits contribute around 47% of total value of primary tree and forest products collected.

Introduction

This criterion describes the quantity, value of different primary and processed tree and forest products collected by the households and the associated employment and income generated for the households. It also estimates the value of different provisional services that households benefit from. It answers questions such as - what is the total income earned by households from primary tree and forest products in each zone and what is the proportion of households receiving benefits from forests? The results are presented at zone and divisional levels. These results are based on socio-economic survey data collected through household survey and the indicators are estimated through using Stata V14. The details of the analysis and estimation procedure are available in Hossain *et al.* (2019). The full questionnaire is available in Appendix 2.2.

Methods

Value and income estimates are derived from data collected about quantity of tree and forest primary products and prices. 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. For estimating value and income from tree and forest products it was necessary to know product price. Price data were gathered from households which sold products. In the case that no price was available for the household, a zone level average price was used. In the cases that no household in the zone reported price, the average of other zones was used. Maps of quantity and value of products were produced by applying the means of zone and HTAC (i.e. Tree Availability strata) to Union polygons.

The zone-specific average values were multiplied with total number of households in the zone to estimate the total quantity or value of different products. A two-factor weight was assigned to per household per year averages of quantity or value, then the national level average was derived as the weighted sum of the zone level estimates. Fisheries products (i.e. fish, shrimp, shrimp fry and crab) contribute heavily in total value of primary tree and forest products, particularly in the Sundarban periphery. Therefore, to understand the effect of fisheries on total estimates, separate estimates that consider only non-fisheries products are also provided for some indicators. Specific methods used for other socio-economic estimations are given in the respective sub-sections. Cells were left blank where there was no sample of that condition and a 0 value indicates < 0.01 of the respective unit. The equations applied are found in the Appendix 9.1 to 9.13. Also see the Appendix 2.1 for details about which land cover classes were aggregated to Forest and Other Land (i.e. TOF).

The quantity and value of Non Wood Forest Products (NWFP) collected from Forests are also presented. NWFP are “goods derived from forests that are tangible and physical objects of biological origin other than wood” FAO (2018) and excludes products from TOF. Households reported collecting from Forest, TOF, or both. Collecting from Forest only represents a low estimate of quantity or value. On the other hand, collection from both Forest and TOF can be added to the Forest only estimate to represent a high estimate. The estimated total value was assumed to be the average of the low and high estimates. The top 10 values are shown in this section and the full results for Forest, TOF, or both are shown in Appendix 9.2 (b, c).

9.1

Primary Tree and Forest Products

9.1.1 Quantity of Each Primary Tree and Forest Products Collected

Description

During the socio-economic survey, households are asked for the quantity of all the primary tree and forest products they collected in the past 12 months and from which land covers they are collected from.The five most common primary products are shown by zone.

The total product quantities are also summarized by Forest and TOF. Most of the primary tree and forest products collected from Forest is in the Hill zone, which is mostly comprised of Hill Forest (Figure 9.1).

Some major primary tree and forest products are collected mainly within specific zones while others are collected across all zones (Table 9.1). Average household level collection of bamboo and fuel wood is highest in the Hill zone, whereas timber and leaves are highest in the Coastal zone.

There is little variation observed in the quantities of fruits collected across zones, though the highest household level collection is in the Village zone. Moreover, in the Village zone the total quantity collected is highest for all the products across zones.

From the Hill and Sundarban periphery zones, households collect a larger variety of products, whereas the variety collected in Sal and Coastal zones is relatively limited (see Appendix 9.1 tables).

Within zones, TOF supply the majority of primary tree and forest products except in the Hill zone. In the Hill zone, about 70% of the timber, bamboo, fuelwood, and leaves, and almost half of the fruits, are supplied from Forest area, presumably near the households. Note that forest cover is also much higher in the Hill zone (74%) compared to other zones (<10%).

The lower quantities of tree and forest products collected from the Sal zone, especially fuelwood, may reflect stronger law enforcement or higher availability of forest product alternatives.

Highlights

- Timber, bamboo, fuel wood, leaves and fruits are the most common primary tree and forest products collected by the households across zones.
- Nationally, TOF are the major supplier of primary products, except in the Hill zone (Figure 9.1).
- The Village zone supplies most of the total collected products, ranging from 81% for timber and 90% for leaves (Table 9.2).

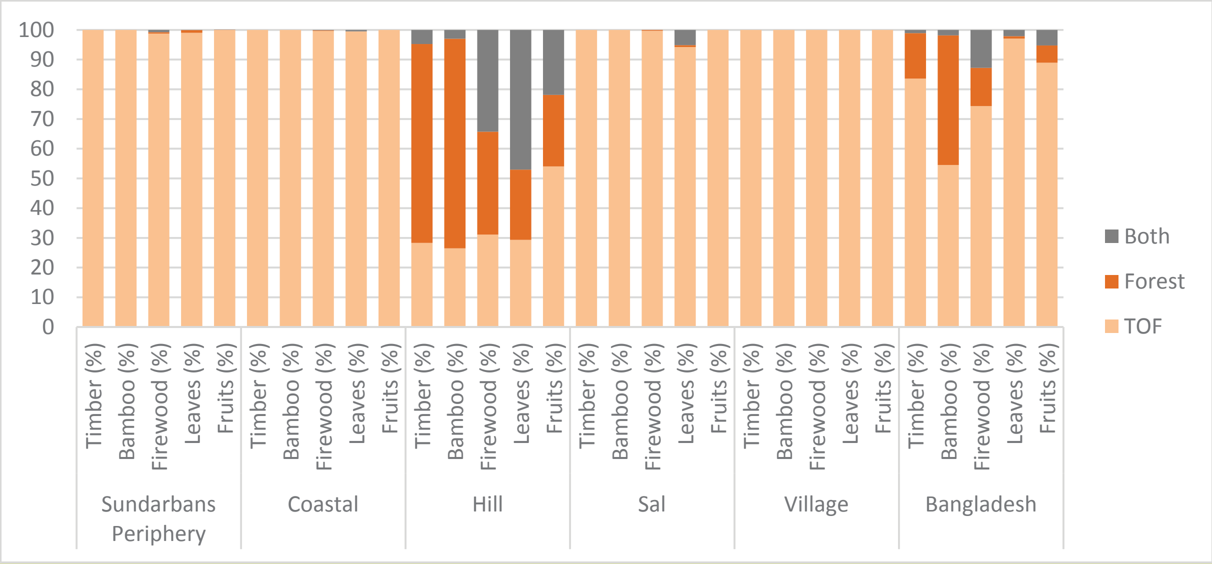


Figure 9.1: Percentage collection of major primary tree and forest products from TOF, Forest, or Both land covers.

Table 9.1: Average quantity of the five most common primary tree and forest products collected by the HHs across zones (Quantity/HH/year).

Zones	Timber (m^3/HH/year)	Bamboo (no/HH/year)	Fuel wood (kg/HH/year)	Leaves (kg/HH/year)	Fruits (kg/HH/year)
Sundarban periphery	0.425	2.614	461.57	827.87	173.28
Coastal	0.581	3.042	1161.08	785.71	162.35
Hill	0.445	27.095	1208.63	183.17	182.96
Sal	0.094	4.482	50.75	350.49	135.19
Village	0.230	9.737	458.23	827.54	198.99
National	0.231	9.291	449.20	752.21	189.58

Table 9.2: Total quantity of the five most common primary tree and forest products collected across zones (quantity/year).

Zones	Timber (m^3/year)	Bamboo (no/year)	Fuel wood (t/year)	Leaves (t/year)	Fruits (t/year)
Sundarban periphery	162,641	1,001,536	176,836	317,170	66,387
Coastal	546,782	2,862,231	1,092,556	739,337	152,771
Hill	387,694	23,582,926	1,051,976	159,429	159,244
Sal	370,747	17,757,559	201,067	1,388,598	535,605
Village	6,185,092	261,953,123	12,327,647	22,263,131	5,353,377
National	7,652,955	307,157,375	14,850,082	24,867,665	6,267,384

9.1.2 Economic Value of Primary Products Collected, including NWFP

Description

The economic value of primary products is the quantity collected multiplied by their prices. Results are summarized in terms of per household and total values, and grouped by zones and Forest and TOF. The quantity and value of Non Wood Forest Products collected from Forests are also presented. The top 10 values are shown in this section and the full results for Forest, TOF, or both are shown in Appendix 9.2 b, c.

The total value of primary tree and forest products collected in Bangladesh is 699,894 million BDT/year, and on an average each household collected 21,171 BDT/year. The Sundarban periphery has the highest average value per household whereas the highest total value occurs in the Village zone (Figure 9.2; Table 9.3; Appendix 9.2a). When fisheries products are removed, the value of primary tree and forest products reduces notably, particularly in Sundarban periphery where value becomes less than half. The Coastal zone then becomes the highest in terms of average income (Table 9.3). In Sundarban periphery and Hill zones, energy products (i.e. fuelwood, leaves, twigs, branches and other energy products) have the highest contribution, which is the second highest contributor at the national level (Figure 9.3).

TOF contribute the most to primary product value, although value from Forest in the Hill zone is also notable (Figure 9.4).

Nationally, and also in the Village, Sal and Coastal zones, fruits harvesting is the highest contributor in value of primary tree and forest products collected (Figure 9.3 and Table 9.4). Fruits also contributed to nearly half of the total value of NWFP collected from Forest area (Table 9.5).

The lower quantities of tree and forest products collected from the Sal zone, especially fuelwood, may reflect stronger law enforcement or higher availability of forest product alternatives.

Highlights

- The total value of primary tree and forest products collected is 3.11% of the 2017-18's national GDP measured in current price. The contribution becomes 2.91% when value of fisheries products is not considered.
- More than 80% of the total value of primary tree and forest products is collected from the Village zone (Table 9.3).

- The lion's share of the average value of primary tree and forest products comes from the TOF areas (nationally 98%). Only in the Hill zone is there substantial contribution from Forest areas (Figure 9.4).
- Fruits collected from Forest were 49% of the total NWFP value, followed by Bamboo (14%) and Honey (11%).

Focus group discussion *©Nikhil Chakma*

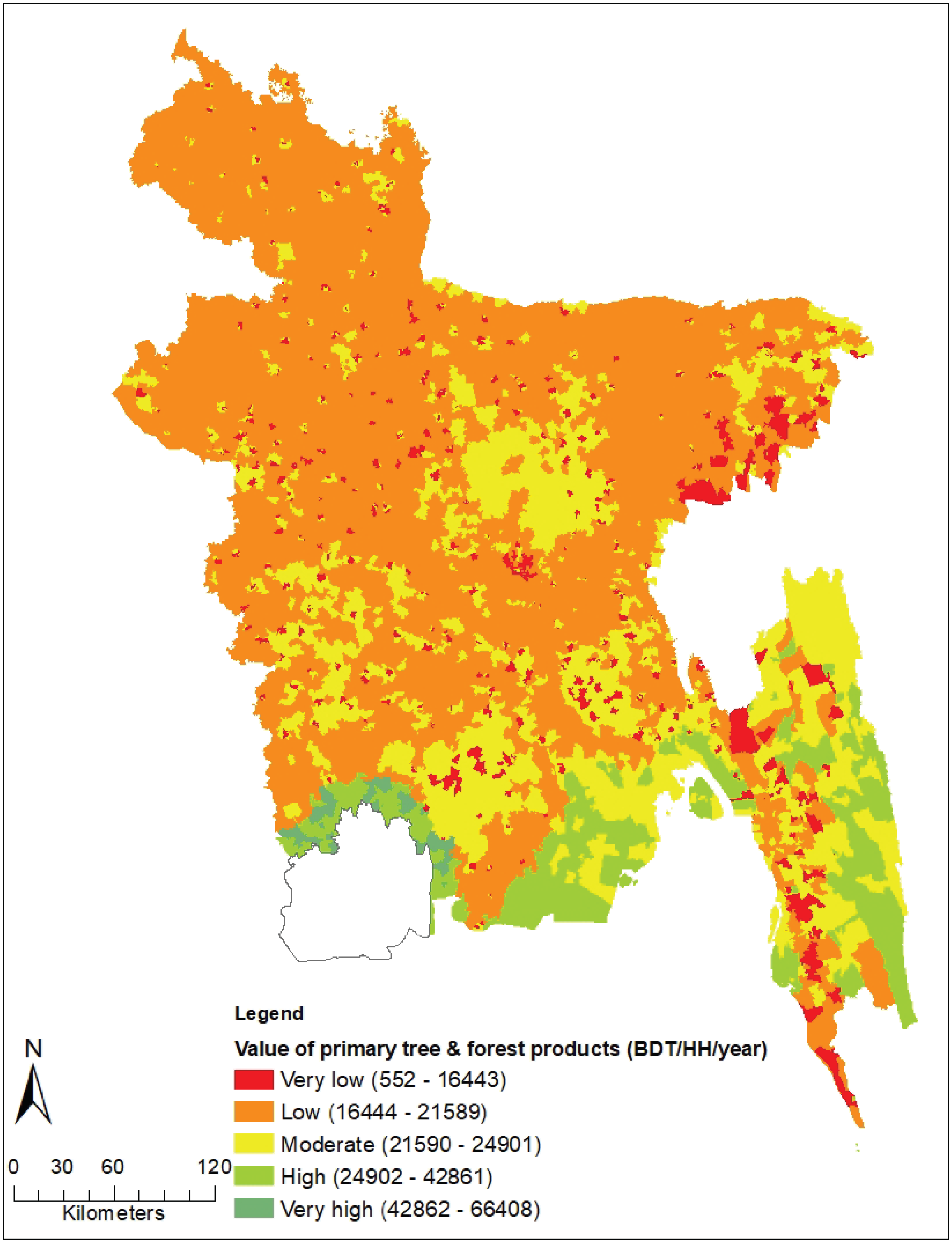


Figure 9.2: Average values (BDT/HH/year) of primary tree and forest products collected by households across zones.

Table 9.3: Values of primary tree and forest products collected by households across zones.

Zone	All primary tree and forest products		Primary tree and forest products excluding fisheries	
	Average value (BDT/hh/year)	Total value (million BDT/year)	Average value (BDT/hh/year)	Total value (million BDT/year)
Sundarban periphery	49,354	18,908	22,697	8,695
Coastal	30,113	28,336	26,402	24,844
Hill	20,509	17,851	18,644	16,227
Sal	13,828	54,784	13,822	54,762
Village	21,560	580,015	20,435	549,763
National	21,171	699,894	19,791	654,292

Table 9.4: Average (BDT/HH/year) and total (million BDT/year) values of different wood and non-wood primary tree and forest products collected by households across zones.

Primary tree & forest products	Unit	Sundarbans periphery	Coastal	Hill	Sal	Villages	National
Timber	BDT/hh/year	3,703.02	6,723.58	3,469.82	2,137.80	2,841.72	2,894.37
	million BDT/year	1,418.69	6,326.78	3,020.08	8,469.71	76,450.65	95,685.91
Poles	BDT/hh/year	621.83	299.03	106.49		120.07	116.24
	million BDT/year	238.23	281.38	92.69		3,230.35	3,842.65
Bamboo	BDT/hh/year	392.28	573.68	1,559.48	489.59	1,547.03	1,379.55
	million BDT/year	150.29	539.83	1,357.35	1,939.71	41,619.70	45,606.86
Brooms	BDT/hh/year	74.16	36.04	228.06	46.61	39.55	45.66
	million BDT/year	28.41	33.91	198.50	184.65	1,063.99	1,509.46
Nypa	BDT/hh/year	142.34					1.65
	million BDT/year	54.53					54.53
Medicinal plants	BDT/hh/year	87.10	10.78	16.12	44.65	59.07	55.16
	million BDT/year	33.37	10.14	14.03	176.89	1,589.28	1,823.72
Murta	BDT/hh/year	10.58	99.34	0.26	0.23	19.36	18.74
	million BDT/year	4.05	93.48	0.23	0.90	520.78	619.44
Tree seedlings	BDT/hh/year	143.18	441.25	10.22		16.51	27.92
	million BDT/year	54.86	415.21	8.89		444.08	923.04
Fodder	BDT/hh/year	7.19	41.86	251.40	7.15	42.00	42.93
	million BDT/year	2.76	39.39	218.82	28.33	1,130.05	1,419.34
Seeds	BDT/hh/year	27.64	19.78	26.93		8.44	8.46
	million BDT/year	10.59	18.61	23.44		227.20	279.83
Fuelwood	BDT/hh/year	3,180.84	4,440.25	4,693.30	507.50	2,543.18	2,417.22
	million BDT/year	1,218.63	4,178.21	4,084.99	2,010.67	68,418.94	79,911.44
Leaves	BDT/hh/year	3,193.63	1,489.44	562.91	1,927.53	3,515.61	3,186.15
	million BDT/year	1,223.53	1,401.54	489.95	7,636.65	94,580.08	105,331.75

Primary tree and forest products	Unit	Sundarban periphery	Coastal	Hill	Sal	Village	National
Fruits	BDT/hh/year	10,254.67	12,201.20	7,089.23	8,649.83	9,507.26	9,426.18
	million BDT/year	3,928.73	11,481.13	6,170.36	34,269.61	255,773.06	311,622.90
Bamboo shoots	BDT/hh/year			128.14			3.37
	million BDT/year			111.53			111.53
Mushroom	BDT/hh/year			99.62			2.62
	million BDT/year			86.71			86.71
Root tubers	BDT/hh/year	30.71		41.29		6.35	6.61
	million BDT/year	11.76		35.94		170.78	218.49
Other vegetables	BDT/hh/year			197.35	3.07	33.27	32.64
	million BDT/year			171.77	12.18	894.96	1,078.91
Spices	BDT/hh/year	5.07	0.10	8.53	7.94	2.87	3.57
	million BDT/year	1.94	0.09	7.43	31.47	77.22	118.15
Other animal products	BDT/hh/year			23.23			0.61
	million BDT/year			20.22			20.22
Fish	BDT/hh/year	7,147.05	3,671.27	1,772.50	5.59	970.78	1,024.66
	million BDT/year	2,738.15	3,454.61	1,542.76	22.13	26,116.89	33,874.53
Shrimp	BDT/hh/year	13,940.19	39.45	72.31		150.71	287.22
	million BDT/year	5,340.71	37.12	62.94		4,054.49	9,495.25
Shrimp fry	BDT/hh/year	742.12					8.60
	million BDT/year	284.32					284.32
Crabs	BDT/hh/year	4,828.08		20.61		3.01	58.94
	million BDT/year	1,849.71		17.94		80.99	1,948.64

Table 9.5: List of top ten Non Wood Forest Products collected from Forest areas only, ranked by value.

Rank	Name of NWFP	Quantity	Unit	Value (million BDT)	NWFP category
1	Fruits	22,810,916	kg/year	1,297.215	Plant Product
2	Bamboo	12,529,474	No/year	374.625	Plant Product
3	Honey	793,423	kg/year	303.190	Animal Product
4	Brooms	1,686,024	bundle/year	177.490	Plant Product
5	Thatching materials	297,534	bundle/year	114.507	Plant Product
6	Bamboo shoots	12,529,474	kg/year	107.373	Plant Product
7	Mushrooms	363,652	kg/year	69.175	Plant Product
8	Other vegetables	2,810,040	kg/year	76.985	Plant Product
9	Root tubers	1,024,838	kg/year	35.502	Plant Product
10	Fodder	8,330,943	kg/year	53.913	Plant Product
All other plant products				34.416	
All other animal products				18.907	
Total				**2,663.300**	

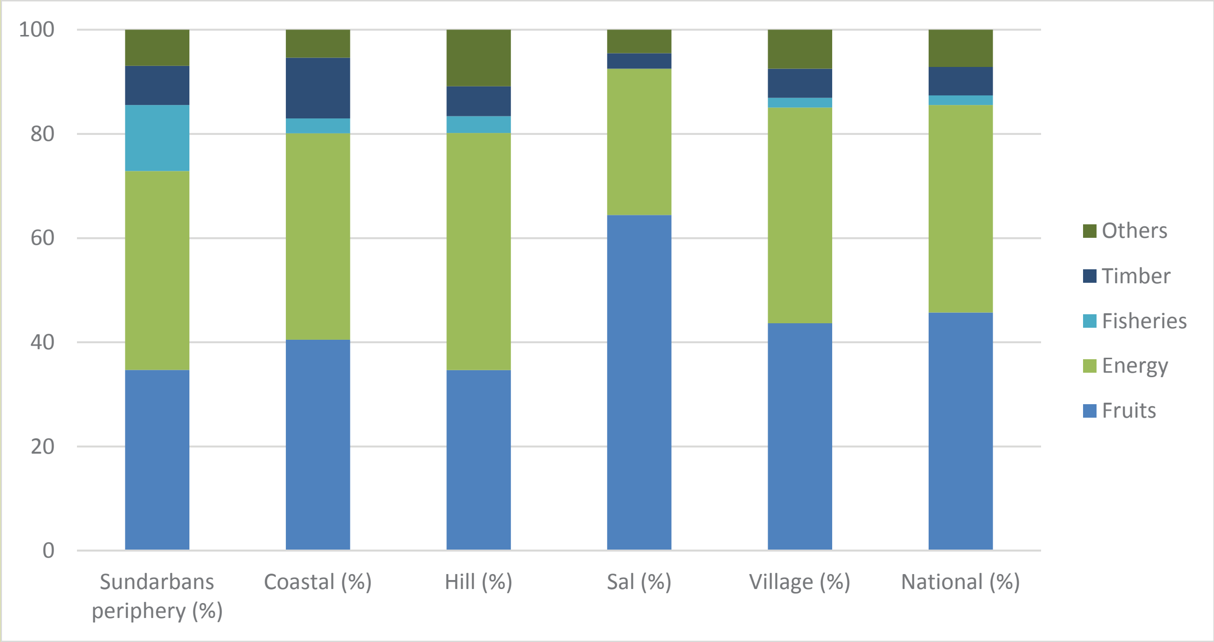


Figure 9.3: Contribution of major products to total value of primary tree and forest (%).

Figure 9.4: Percentage of value of primary tree and forest products from TOF, Forest, or Both land covers.

9.1.3 Quantity/Share of Collected Primary Products Sold

Description

Households sell a variety of tree and forest products that they collect (Table 9.6). More than 2.1 million tons of fruit, 434, 100 tons of fishery products and 4,448 million tons of timber are annually sold.

Some products are sold across all zones (e.g. timber, fuelwood, bamboo, fish, fruits, etc.), whereas others are zone specific (e.g. Nypa and shrimp fry in the Sundarban periphery, poles in Sundarban periphery and Coastal zones, etc.) (Appendix 9.3 tables). The total quantity sold in the Village zone is the highest compared to other zones.

In terms of the proportion of the collected products that are sold, Fruits is the highest at 10.3%, followed by Timber at 7.2%, and Bamboo at 5.7%. For most products, households in the Coastal and Sundarban periphery zones sold a higher percentage of the products they collected.

Highlights

- 458,513 tons are annually collected for cooking and heating by households (see 9.5.1 for their value).
- Households sell a very small portion of the products they collect, suggesting they collect these products mostly for their own use and subsistence (Table 9.7).
- Regarding the products sold across all zones (e.g. timber, bamboo, fuelwood, leaves, fruits, and fish) the Village zone sells at least 70% of the national quantity (Appendix 9.3 tables).

Table 9.6: Total annual quantity (quantity/year) of different primary tree and forest products sold by households at national scale.

Primary tree and forest products		Annual quantity
Timber (m^3/year)		4,448,173
Poles (no/year)		306,607
Bamboo (no/year)		152,475,809
Medicinal plants (kg/year)		327,001
Murta (no/year)		906,904
Fodder (kg/year)		371,641
Brooms (bundles/year)		2,284,504
Nypa (bundles/year)		320,648
Tree seedlings (bundle/year)		4,178,220
Seeds (kg/year)		9,644
Fruits (kg/year)		2,092,782,915
Bamboo shoots (kg/year)		252,375
Mushroom (kg/year)		20,935
Root tubers (kg/year)		216,460
Other vegetables (kg/year)		342,859
Spices (kg/year)		1,206,459
Other animal products (kg/year)		66,080
Fish (kg/year)		183,896,683
Shrimp (kg/year)		23,536,583
Shrimp fry (no/year)		222,598,710
Crabs (kg/year)		4,068,851
Energy products used for cooking & heating	Fuelwood (kg/year)	414,214,511
	Leaves (kg/year)	44,298,624

Table 9.7: Share of the collected quantity sold for six of the most common primary tree and forest products (%).

Zone	Timber	Bamboo	Fuelwood	Leaves	Fruits	Fish
Sundarban periphery	7.6	2.6	0.6	0.5	14.4	6.3
Coastal	11.3	4.5	1.0	0.7	13.0	2.8
Hill	7.2	6.1	1.2		11.0	2.0
Sal	1.7	3.8	0.0	0.0	6.7	0.0
Village	7.9	6.0	0.8	0.1	10.6	1.1
National	7.2	5.7	0.7	0.1	10.3	1.1

9.1.4 Annual Income earned by the Households from Selling Primary Tree and Forest Products

Description

The gross income that a household earns from selling primary tree and forest products was estimated by multiplying the selling quantities with price. Then the associated selling cost was deducted to know the household's net income. Similar to primary tree and forest products, total annual income was estimated both with and without income from fisheries products.

In most of the parts of the country, particularly in the Village zone, households income earned from primary tree and forest product is low (Figure 9.5 and Table 9.8). On average, a household annually earns BDT 6,664 from selling primary tree and forest products and the total national income generatedis more than 220 billion BDT (Table 9.8).

When fishery products are removed from the national annual income, it reduces by about 33 billion BDT, or 15% (Table 9.8). Fruits and timber are the major contributor in income in most of the zones, but to varying degrees (Figure 9.6). To note that a portion of the Sundarbans is protected area where fishing is banned, but likely supplies fishery resources to adjacent limited use areas. Thus, conservation efforts are providing income to fishermen from surrounding communities.

In the Hill and Sal zones, households with greater access to tree and forest resources may receive more income from selling forest products. The higher Household Tree Availability Classes (HTAC) had relatively higher average income than their counterparts belonging to the relatively lower HTAC (Appendix 9. 4). In other three zones, no such correlations are observed.

Highlights

- A household in the Sundarban periphery earned more from selling than their counterparts living in other zones, contributed mainly by shrimp and crab.
- More than three-fourth of the total annual income is earned by the households living in the Village zone (Table 9.8).
- Income from fruit is the major contributor to income in all the zones, except Sundarban periphery, where households earn highest portion of their annual income from shrimp (Figure 9.6).

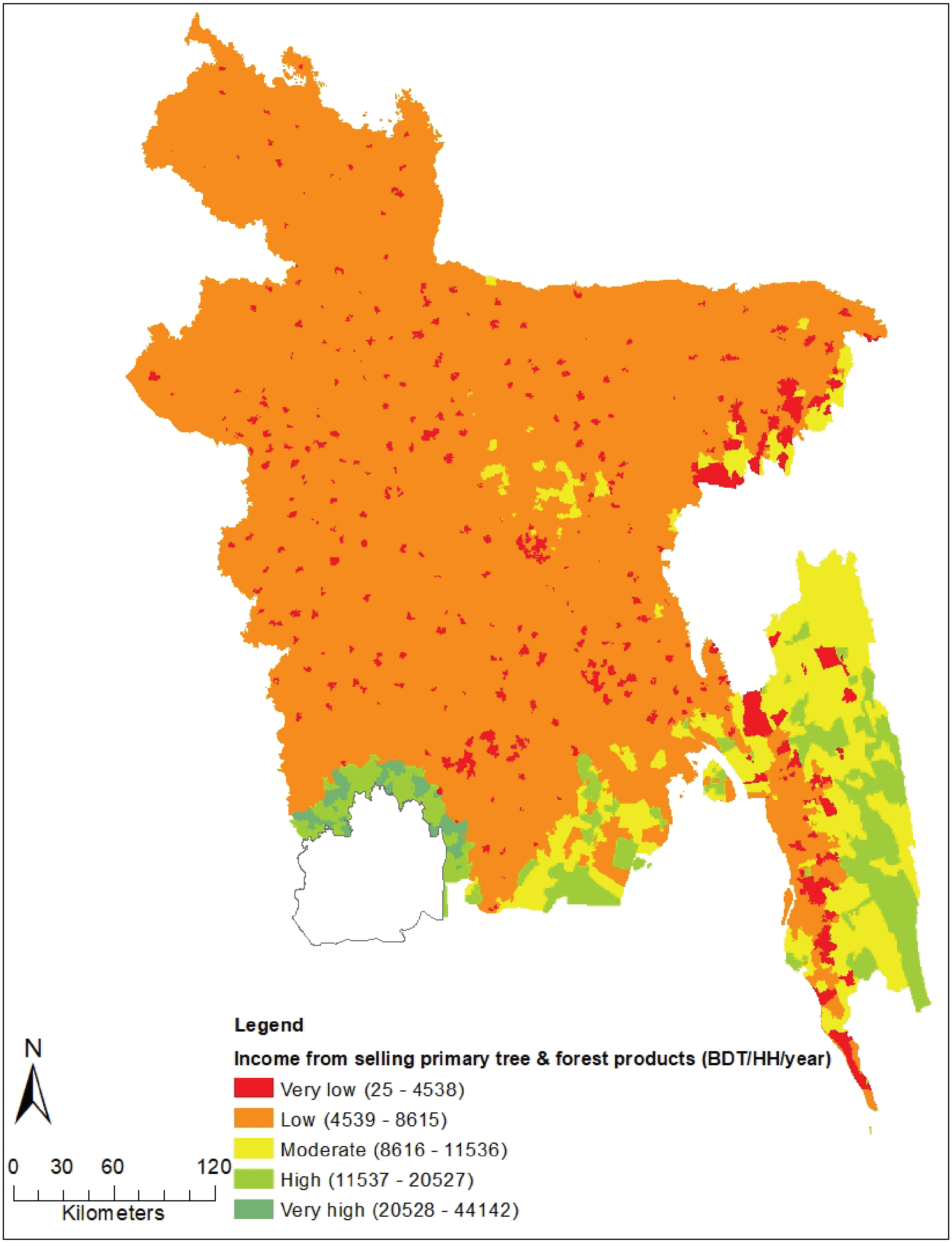


Figure 9.5: Average income (BDT/HH/year) from selling primary tree and forest products collected by households across zones.

Table 9.8: Income from primary forest products by zone and product type.

Primary tree and forest products	Unit	Sundarban periphery	Coastal	Hill	Sal	Village	National
Timber	BDT/hh/year	1,561.90	2,519.65	2,683.22	580.03	1,698.45	1,612.14
	million BDT/year	598.39	2,370.95	2,335.44	2,298.03	45,693.28	53,296.09
Poles	BDT/hh/year	17.13	3.84				0.31
	million BDT/year	6.56	3.61				10.17
Bamboo	BDT/hh/year	201.11	200.50	995.24	355.40	711.79	656.07
	million BDT/year	77.05	188.67	866.25	1,408.06	19,149.26	21,689.28
Brooms	BDT/hh/year	8.28	0.67	104.70		0.87	3.58
	million BDT/year	3.17	0.63	91.13		23.33	118.26
Nypa	BDT/hh/year	36.79					0.43
	million BDT/year	14.10					14.10
Medicinal plants	BDT/hh/year	1.01		3.94	0.45		0.17
	million BDT/year	0.39		3.43	1.77		5.58
Murta	BDT/hh/year		22.15			4.91	4.63
	million BDT/year		20.84			132.12	152.96
Tree seedlings	BDT/hh/year	14.17	52.67				1.66
	million BDT/year	5.43	49.56				54.99
Fodder	BDT/hh/year				0.28		0.03
	million BDT/year				1.11		1.11
Seeds	BDT/hh/year			3.32			0.09
	million BDT/year			2.89			2.89
Fuelwood	BDT/hh/year	56.74	102.26	221.16	0.21	56.22	55.17
	million BDT/year	21.74	96.23	192.50	0.83	1,512.53	1,823.82
Leaves	BDT/hh/year	13.66	17.39		1.31	4.95	4.84
	million BDT/year	5.23	16.37		5.18	133.21	159.99
Fruits	BDT/hh/year	3,564.28	4,810.95	3,220.09	4,274.38	2,996.76	3,213.96
	million BDT/year	1,365.53	4,527.03	2,802.72	16,934.57	80,621.58	106,251.42
Bamboo shoots	BDT/hh/year			6.82			0.18
	million BDT/year			5.94			5.94
Mushroom	BDT/hh/year			3.54			0.09
	million BDT/year			3.08			3.08
Root tubers	BDT/hh/year	2.75		8.08			0.24
	million BDT/year	1.05		7.03			8.09

Primary tree and forest products	Unit	Sundarban periphery	Coastal	Hill	Sal	Village	National
Other vegetables	BDT/hh/year			3.78	1.16		0.24
	million BDT/year			3.29	4.59		7.88
Spices	BDT/hh/year	1.50		6.04	7.87	2.73	3.34
	million BDT/year	0.57		5.26	31.20	73.36	110.39
Other animal products	BDT/hh/year			2.49			0.07
	million BDT/year			2.17			2.17
Fish	BDT/hh/year	5,715.76	3,139.59	1,210.37	2.00	678.07	739.51
	million BDT/year	2,189.80	2,954.31	1,053.48	7.93	18,242.19	24,447.71
Shrimp	BDT/hh/year	11,619.95	30.88	41.76		82.20	203.53
	million BDT/year	4,451.79	29.06	36.35		2,211.43	6,728.63
Shrimp fry	BDT/hh/year	726.23					8.42
	million BDT/year	278.23					278.23
Crabs	BDT/hh/year	4,319.47		3.31		3.01	52.59
	million BDT/year	1,654.86		2.88		80.99	1,738.73
All products	BDT/hh/year	28,638.50	10,902.61	8,527.02	5,223.09	6,355.26	6,664.43
	million BDT/year	10,971.87	10,259.18	7,421.80	20,693.25	170,975.13	220,321.23
All products excluding fisheries	BDT/hh/year	6,257.09	7,732.13	7,271.58	5,221.09	5,591.97	5,660.37
	million BDT/year	2,397.19	7,275.81	6,329.08	20,685.33	150,440.50	187,127.91

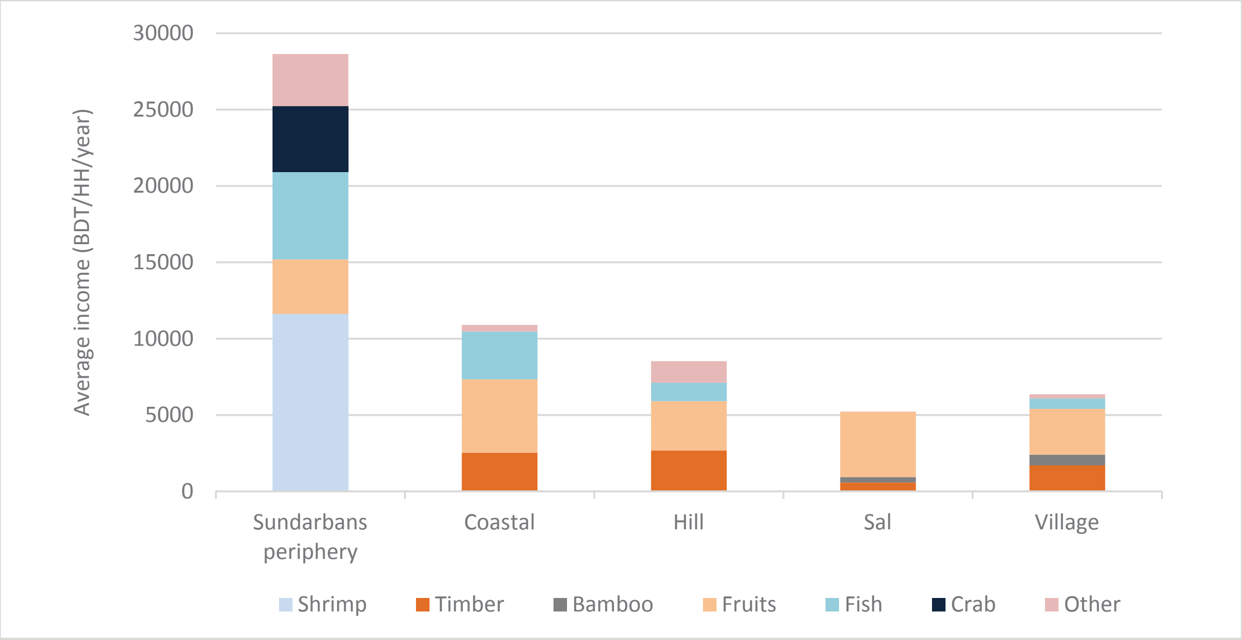


Figure 9.6: Income from different primary tree and forest products across zones.

9.2

Processed Tree and Forest Products

9.2.1 Quantity of the Processed Tree and Forest Products

Description

During the socio-economic survey, the households were asked about the quantity of different processed tree and forest products that they produced in the past 12 months.

Wooden furniture and handicrafts are the two most common processed tree and forest products. In the Village zone, households produce highest quantity of wooden furniture, wooden agricultural appliances and handicrafts. But average household level production is highest in Sundarban periphery for wooden furniture and handicrafts (Table 9.9 and 9.10).

Highlights

- The number of products processed per household is notably high in the Sundarban periphery zone and low in the Sal zone.
- Production of wooden furniture is highest in the Village zone, followed by Sundarban periphery, Sal, Hill and Coastal zones (Table 9.10).
- In the case of handicrafts, the highest quantity is produced in the Village followed by Coastal, Hill, Sal and Sundarban periphery zones (Table 9.10).

Table 9.9: Average quantity of tree and forest products processed across zones (No/HH/year).

Zone	Wooden furniture (No/HH/year)	Wooden agricultural appliances (No/HH/year)	Handicrafts (No/HH/year)
Sundarban periphery	0.895		2.415
Coastal	0.030		2.766
Hill	0.098		1.871
Sal	0.047	0.008	0.274
Village	0.092	0.014	0.154
National	0.094	0.012	0.314

Table 9.10: Total quantity of tree and forest products processed across zones (No/year).

Zone	Wooden furniture (No/year)	Wooden agricultural appliances (No/ year)	Handicrafts (No/year)
Sundarban periphery	343,060		925,087
Coastal	28,581		2,602,351
Hill	85,325		1,628,747
Sal	187,492	33,207	1,085,019
Village	2,465,742	379,135	4,144,781
National	3,110,200	412,342	10,385,985

9.2.2 Quantity of the Processed Tree & Forest Products Supplied to the Market by Households

Description

The surveyed households reported to sell two broad categories of processed products: wooden furniture and handicrafts. The highest quantity of handicraft is sold in the Coastal zone, followed by Village, Hill, Sal and Sundarban periphery. In the Village zone, highest quantity of wooden furniture is sold, though average household level quantity is highest in the Sal zone (Table 9.11).

Highlights

- As with primary tree and forest products, households sell very little processed products, probably because they are for household use.
- Handicraft is the most common product sold across zones.
- The number of handicrafts produced is higher in the Coastal zone compared to others.
- The quantity of wooden furniture sold is highest in the Village zone due to a larger number of total households.

Table 9.11: Quantity of the processed tree and forestproducts supplied to the market by households.

Zones	Wooden furniture		Handicrafts	
	No/HH/year	No/year	No/HH/year	No/year
Sundarban periphery	0.070	26,812	1.653	633,105
Coastal	0.001	531	2.304	2,167,737
Hill	0.000	0	1.729	1,504,682
Sal	0.047	185,884	0.242	960,554
Village	0.013	343,916	0.073	1,954,581
National	0.017	557,143	0.218	7,220,660

9.2.3 Annual Income Earning from Processed Tree and Forest Products

Description

The gross income from processed tree and forest products was estimated by multiplying the quantity sold with price. Then, the associated selling cost was deducted to know the zone-specific net income (BDT/HH/year).

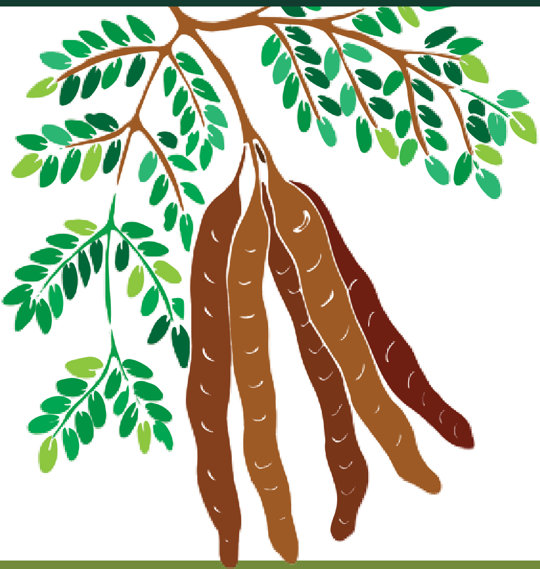
The annual income earned from selling processed products is limited. Though a household in the Coastal zone earned higher than their counterparts living in other zones, total income is highest in the Village zone. The Village zone contributed more than half of the total income from processed products (Table 9.12).

Highlights

- In the Village zone, total household income from processed products is higher than in other zones.
- The total annual national income from processed tree and forest products is 1,994 million BDT.
- Processed tree and forest products represent 0.01% of the Gross National Income measured in current market price.

Table 9.12: Income from processed tree and forest products across zones.

Zone	Average income (BDT/hh/year)	Total income (million BDT/year)
Sundarban periphery	45.18	17.31
Coastal	512.43	482.19
Hill	271.28	236.12
Sal	28.46	112.74
Village	42.60	1,146.11
National	60.33	1,994.47



9.3

Involvement with Tree and Forest Related Activities

9.3.1 Number and Proportion of Household Members Involved/Employed in Tree & Forest Related Activities

Description

During the socio-economic survey respondents were asked for the number of household members involved with different tree and forest related activities during the last 12 months.

For those households which were involved with tree and forest related activities, about three members per household collected primary tree and forest products, with the highest members per household in the Village zone (Table 9.13).

Primary tree and forest product collection is also the main tree and forest related activity in terms of total number of people, involving 105.5 million people annually at the national scale (Table 9.14). This is 64% of the total population compared to only 1.7% and 0.1% for processing and selling activities, respectively.

Nationally, 53.3 million women collect primary tree and forest products. More women per household in the Sundarban periphery, Coastal, and Hill zones were involved with processing and selling tree and forest products than in the Sal and Village zones (Table 9.15).

Highlights

- More people in the Village zone (both in terms of number and proportion) were involved with primary tree and forest product collection than other zones (Table 9.13 and 9.14).
- 64% of the total national population is involved in collecting primary tree and forest products (Table 9.14).
- Women involvement in collecting tree and forest resources is significant. Around 65% of the country's total women population were involved with collecting primary tree and forest products (Table 9.15).

Table 9.13: Average number of members per household (rounded) involved with tree and forest related activities across zones (no. members/HH/year).

Zone	Primary tree and forest product collection[1]	Processing tree and forest products[1]	Selling of processed tree and forest products[1]
Sundarban periphery	3 (71.85)	<1 (6.80)	<1 (0.17)
Coastal	3 (50.66)	<1 (3.18)	<1 (0.76)
Hill	3 (49.70)	<1 (4.64)	<1 (0.32)
Sal	2 (36.66)	<1 (0.48)	<1 (0.07)
Village	4 (74.00)	<1 (1.67)	<1 (0.10)
National	3 (68.20)	<1 (1.71)	<1 (0.12)

[1]Figures in parentheses are percentages of family members per household involved with tree and forest related activities.

Table 9.14: Total number of persons involved in tree and forest related activities across zones (no. persons/year).

Zone	Primary tree and forest product collection	Processing tree and forest products	Selling of the tree and forest products
Sundarban periphery	1,274,009	119,359	3,699
Coastal	2,578,732	184,299	38,317
Hill	2,244,640	197,518	14,934
Sal	6,634,689	79,075	11,720
Village	92,737,689	2,215,117	117,186
National	105,469,759	2,795,368	185,856
% of total population	64.04	1.70	0.11

Table 9.15: Women involved with tree and forest related activities across zones (no. women/year).

Zone	Primary tree and forest product collection	Processing the tree and forest products	Selling of the tree and forest products
Sundarban periphery	636,805	66,615	2,057
Coastal	1,283,972	159,970	18,406
Hill	1,074,525	62,176	8,357
Sal	3,561,057	35,012	2,088
Village	46,718,852	981,648	0
National	53,275,211	1,305,421	30,908
% of women population	65.53	1.61	0.04

9.4

Services and Benefits from Trees and Forests

Description

The proportion of households in a zone receiving a forest related service was estimated as the ratio of total service recipient households and total number of households surveyed in the zone, adjusted by a two-factor weight.

Households not only earn their livelihood from tree and forests, but also benefit from several other essential services. A high proportion of households benefiting from different tree and forest related services may indicate for high level of interaction between human and tree and forests. Among different tree and forest related livelihood options, highest proportion of households were involved with primary tree and forest products (Table 9.16 and 9.17).

Few of the households earn income from co-management and social forestry. In the Sal and Village zones, no household reported to earn from co-managed forestry (Table 9.16). Only 0.2% households participate in social forestry programs according to respondents.

The FD also has records from social forestry participation which indicate 2% of households participate in social forestry from 1981 to 2018. The FD figure is cumulative over many years, in contrast to the socio-economic survey, which is a snapshot of the current number of beneficiaries.

Highlights

- All the households have received at least one tree and forest related service (Table 9.16 and 9.17), which indicates very high level of interactions between trees and forest and human in Bangladesh.
- Among the livelihood related services, collection of primary tree and forest products is the most common, particularly in Sundarban periphery, Village, Hill and Coastal zones. Primary tree and forest products contribute in income of one out of every three households (Table 9.16).
- Shade, natural windbreak, pollution control, medicinal, soil quality and fertility are the most common services enjoyed by the households (Table 9.17).

Table 9.16: Percentage of HH receiving different livelihood services from tree and forest related services.

Zones	Collection and production of tree and forest products		Tree and forest as source of income			
	Collection of primary tree and forest products	Producing tree and forest products	Primary tree and forest products	Processed tree and forest products	Co-managed forestry	Social forestry
Sundarban periphery	99.47	23.37	47.62	0.67	1.51	0.41
Coastal	94.70	11.27	36.62	2.77	0.15	0.07
Hill	95.31	14.79	28.73	1.48	0.50	0.71
Sal	52.65	0.80	14.85	0.24	0.00	0.11
Village	97.56	6.13	31.65	0.40	0.00	0.17
National	92.06	6.07	29.89	0.48	0.04	0.18

Table 9.17: Percentage of HH receiving different services/benefits from tree and forest.

Services/benefits	% of HHs
Shade	94.51
Natural windbreak	86.93
Pollution control	65.33
Medicinal	53.29
Soil quality and fertility	51.26
Erosion control	40.09
Livestock grazing	25.16
Tourism	12.14
Recreation	15.09
Aesthetic	14.26
Religious/ spiritual	7.18
Freshwater/ water conservation	5.88
Others	21.47

9.5

Dependence on Trees and Forests for Energy

9.5.1 Value of Collected Forest Products Used for Cooking and Heating

Description

The value of the tree and forest products that a household collects for heating and cooking purposes was estimated by multiplying the quantities of fuel wood and leaves collected with the price. The price here was the price at which the households sold the products.

The national level total value of products used for cooking and heating is 202,927 million BDT/year. The Village zone has the highest total value among all zones, followed by Hill, Sal, Coastal and Sundarban periphery. The average household level collection is by far the highest in the Hill zone, followed by Sundarban periphery, Village, Coastal and Sal zones (Table 9.18).

Highlights

- The national average amount of forest products collected for cooking and heating is 1,442 kg/HH/year,
- The Hill zone average value of cooking and heating forest products is four times higher than the national average.
- The Sal zone collected 2.4 times less forest products for cooking and heating than the national average, perhaps because this more urbanized zone is using more alternative fuels than other zones.
- 80% of the total national value is from the Village zone (Table 9.18).

Table 9.18: Amount and value of collected forest products used for cooking and heating.

Zone	kg/HH/year	BDT/HH/year	Million BDT/year
Sundarban periphery	1,579	8,869	3,398
Coastal	2,263	5,930	5,580
Hill	1,737	24,476	21,303
Sal	593	2,435	9,647
Village	1,527	6,059	162,999
National	1,442	6,138	202,927

9.5.2 Cost of Forest Products Used for Cooking and Heating

Description

Households were asked '*How much money is required per month for buying [any energy product]?*' Households purchase different types of energy products including fuelwood, leaves and other tree biomass, charcoal, briquette, LP gas, kerosene, biogas, cow dung and agricultural residues. The total cost for these products at the national level is estimated to be 84,419 million BDT, with highest cost in the Village zone (Table 9.19).

Highlights

- Households in the Coastal zone spend more on energy from tree and forest products than households in other zones (Table 9.19).
- In all zones except the Sal zone, households spend more on energy products with lower access to tree and forest resources. The amount spent decreased in higher Household Tree Availability Classes (HTAC) (Figure 9.7).

Table 9.19: Cost of buying forest products used for cooking and heating.

Zone	BDT/HH/year	million BDT/year
Sundarban periphery	1,695	649
Coastal	3,979	3,744
Hill	3,210	2,794
Sal	2,842	11,261
Village	2,452	65,970
National	2,554	84,419

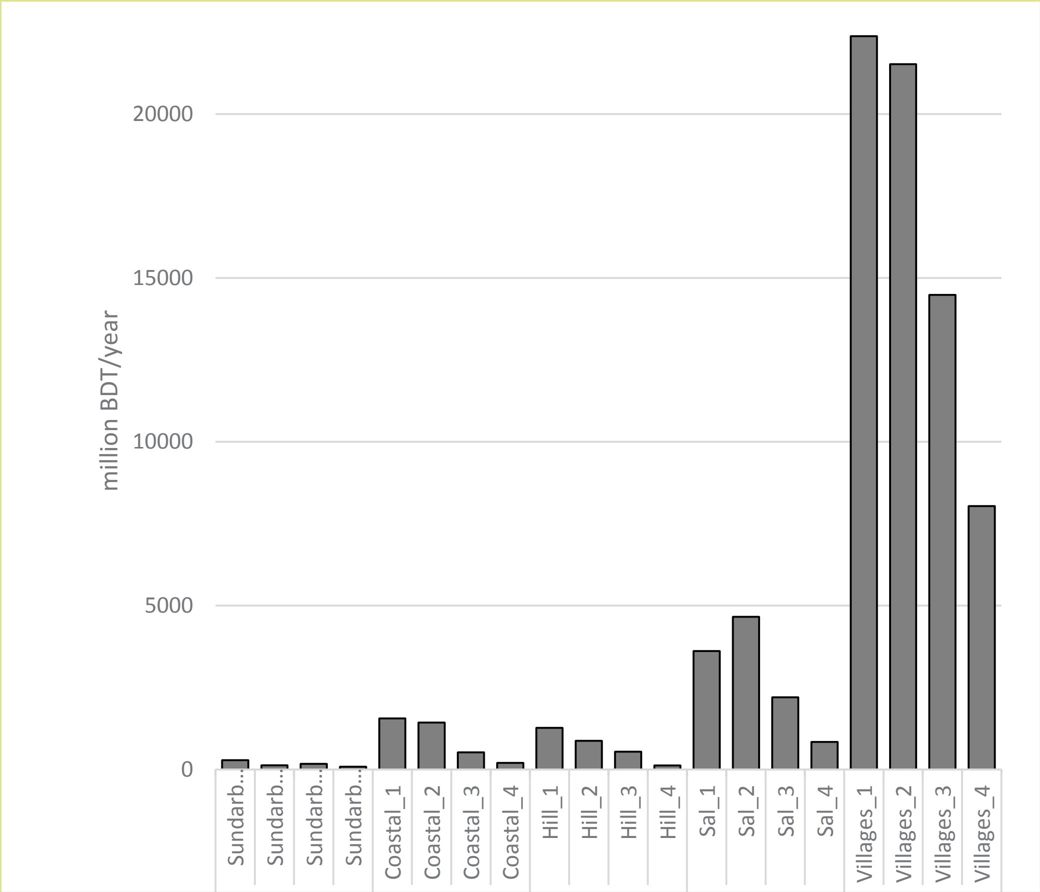


Figure 9.7: Cost of buying forest products used for cooking and heating across Household Tree Availability Classes (HTAC).

9.5.3 Presumed Amount of Purchased Tree and Forest Products Used for Energy

Description

The difference between consumption and collection of tree and forest products used for energy is the presumed amount of purchased energy products. This simplified metric ignores that the household may benefit from the collection of fuelwood or leaves from others at no cost.

Annuallyhouseholds purchase 8,946,504 tons of fuelwood from the market. For leaves, except Sundarban periphery and Sal, households do not purchase from market (Table 9.20).

The reason that zones with more urbanized areas, such as the Sal and Village zones, have lower purchased amounts may reflect that more gas and other sources of energy are purchased in these areas.

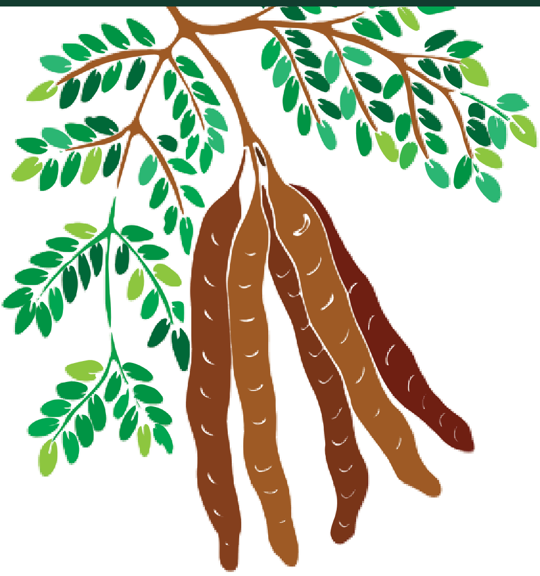
Highlights

- About 82% of purchased fuelwood at the national level comes from Village zone.
- The Village zone has the highest surplus of leaves, i.e. after meeting the demand for cooking and heating purposes, households here possess enough to be used for other purposes.

Table 9.20: Presumed amount of purchased tree and forest products used for energy.

Zone	Fuelwood		Leaves		Energy (both fuelwood and leaves)	
	kg/HH/year	t/year	kg/HH/year	t/year	kg/HH/year	t/year
Sundarban periphery	261.97	110,632	27.41	11,574	289.37	122,205
Coastal	351.51	364,602	-34.97	-36,270	316.54	328,332
Hill	347.26	333,173	-2.43	-2,335	344.83	330,839
Sal	189.23	826,423	2.72	11,870	191.95	838,294
Village	246.55	7,311,674	-5.41	-160,515	241.14	7,151,158
National	245.50	8,946,504	-4.82	-175,676	240.68	8,770,828

Note: Purchased Amount = Consumed Amount – Collected Amount. A negative sign means households have surplus, which may be used for other purposes.



9.6

Total Annual Income from Trees and Forests

Description

Total annual income from trees and forests includes income from selling primary or processed products (sections 9.1.4 and 9.2.3) and also income from other services (section 9.4). Total national income from tree and forest is 302,812 million BDT/year. The largest contribution is from the Village zone though it also has the lowest average annual income. A household in the Sundarban periphery has three times higher annual income from tree and forests than the national average (Table 9.21).

Nationally around 3.5% of a household's annual income came from trees and forests (Table 9.22). Contribution from tree and forest to annual income is the highest in the Sundarban periphery (9.0%) and the lowest in the Sal zone (2.6%). In addition, the percent of annual income increased with increasing access to trees and forests (i.e. HTAC), as much as 15% in the Sundarban periphery and 12% in the Hill (Appendix 9.2a).

Nationally, households belonging to the middle-income group (3rd 60%) earned relatively high income from trees and forests than other quintiles. Notable differences existed across zones however. For instance, in the Sundarban periphery the top quintile earned at least 1.5 times higher than any other quintile. This may be due to greater ability in this quintile to obtain necessary investments, especially for fishery products. In the Sal zone, tree and forest income has the lowest contribution, which may be due to relatively high level of urbanization (Figure 9.8). Households belonging to higher income classes earn more from tree and forest products, which suggests those income levels are benefitting more financially from tree and forest resources (Figure 9.9).

Highlights

- The total income from tree and forest is 1.29% of the 2017-18's national GNI measured in current market price. The contribution reduced to 1.15% when fisheries products are not considered.

- The Village zone alone contributes more than three-fourths of the total national forestry income (Table 9.21).
- A household in the Sundarban periphery earned the highest from trees and forests than in other zones when fishery products are included (Table 9.21). When fishery products are excluded, about three-fourths of the income is reduced.
- At the national level, both average and total income reduces by around 11% when fisheries products are not considered (Table 9.21).
- Households belonging to higher income classes earn more from tree and forest products (Figure 9.9), though in terms of share to total income there do not exist any clear pattern (Figure 9.8).

Table 9.21: Household's total annual income from tree and forest products.

Zone	Income[1]		Income excluding fisheries[1]	
	Average income (BDT/HH/year)	Total income (million BDT/year)	Average income (BDT/HH/year)	Total income (million BDT/year)
Sundarban periphery	29,275	11,216	6,893	2,641
Coastal	12,362	11,632	9,191	8,649
Hill	14,703	12,797	13,447	11,704
Sal	9,347	37,032	9,345	37,024
Village	8,554	230,135	7,791	209,601
National	9,160	302,812	8,156	269,644

[1]Estimated by adding income from different tree and forest related activities (i.e. income from primary and processed products, salary).

Table 9.22: Percentage of total annual income received by households from forest.

Zone	Percentage of total annual income[1]
Sundarban periphery	9.02
Coastal	5.45
Hill	6.86
Sal	2.56
Village	3.40
National	3.52

[1]Estimated as the ratio of total tree and forest income and total annual income.

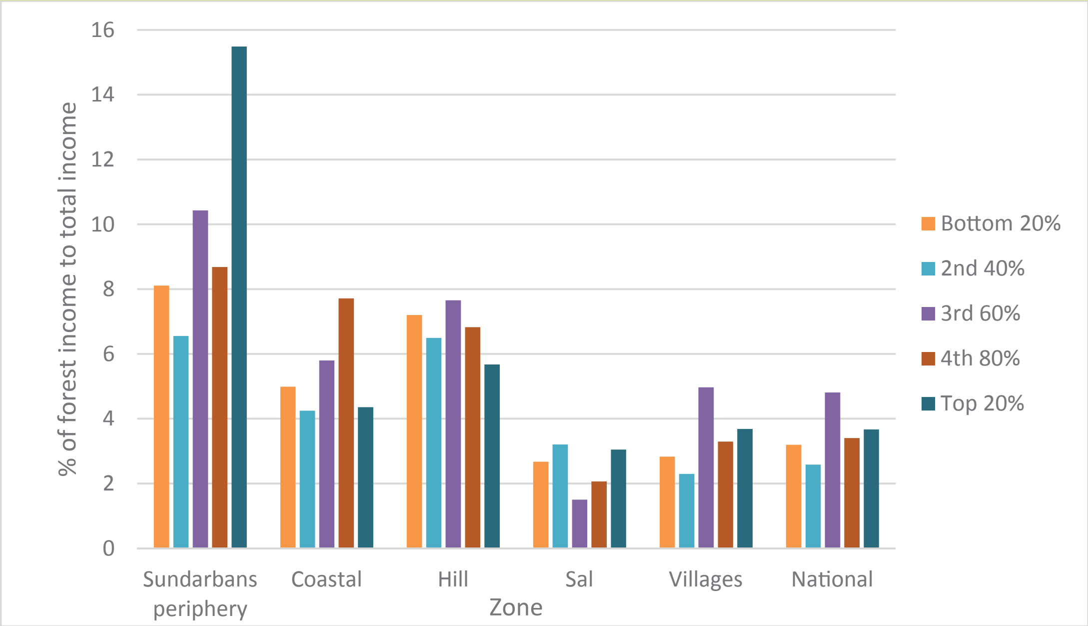


Figure 9.8: Share of income from forestry to total income by different income quintiles across zones (%).

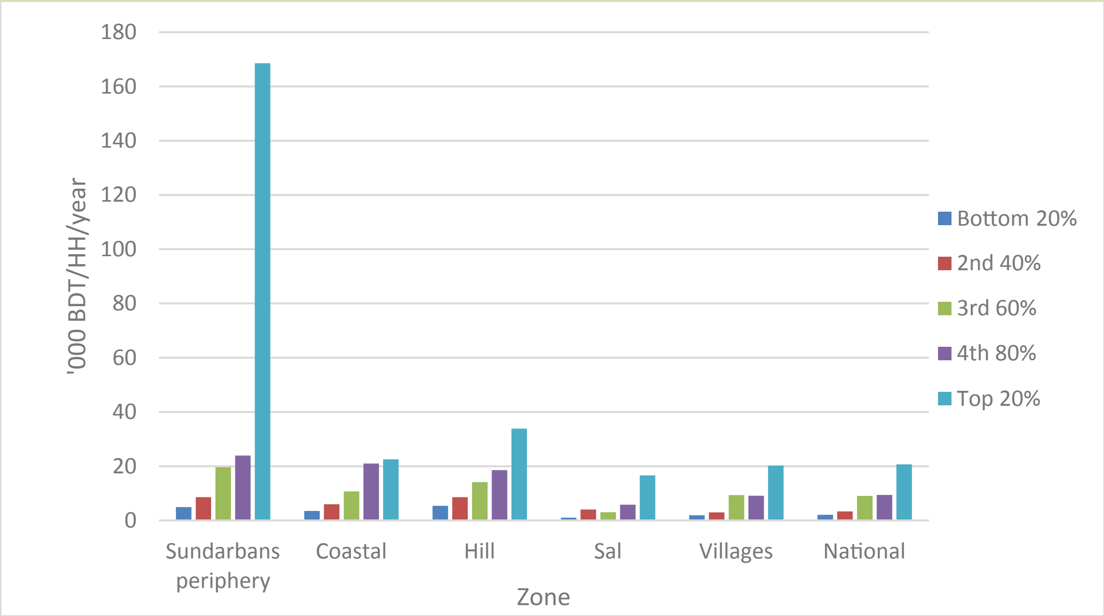


Figure 9.9: Average income (BDT/hh/year) from tree and forest by different income quintiles across zones. Note: Instead of weighted sum of all the zones, the National average was estimated using the same technique used for zones, as household numbers by quintiles across zone are unknown.

Flowering of sal tree ©Mariam Akhtar

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