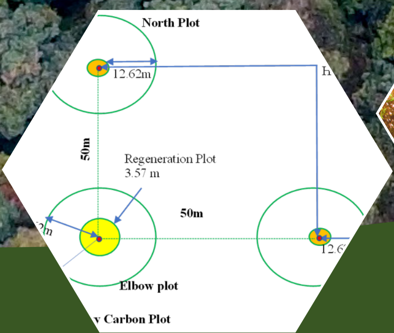
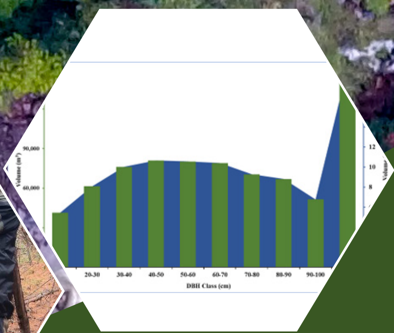
NATIONAL FOREST INVENTORY

VOLUME II







STATE OF FOREST CARBON REPORT

June, 2023

Forest Monitoring and Information Division
Department of Forests and Park Services

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Lobzang Dorji, Director, DoFPS

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VOLUME II: *STATE OF FOREST CARBON REPORT*

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Department of Forests and Park Services

MESSAGE FROM THE HON'BLE SECRETARY, MoENR

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Ministry of Energy and Natural Resources
Royal Government of Bhutan
Thimphu

BHUTAN
Believe

SECRETARY

I commend the Department of Forests and Park Services for completing the 2nd National Forest Inventory and coming out with the two reports; (i) National Forest Inventory Volume I: State of Forest Report, and the (ii) National Forest Inventory Volume II: State of Forest Carbon Report. These reports provide estimates of the forest area and growing stock in addition to information on forest health and disturbance and the carbon stock of Bhutan.

This information is important for monitoring extent of forest area, timber resources, forest health, forestry management, carbon sequestration, which are integral components of informed decision making and supporting international, regional and national policy making. In addition, these shall help guide the long-term planning of the Department of Forests and Park Services and the Ministry of Energy and Natural Resources in fulfilling goals of our 13th Five Year Plan and the Long-term Plan of the Ministry and the Royal Government of Bhutan.

The 2nd NFI is a part of periodic exercise to monitor the changes in the states of forest resources of Bhutan and guide us in ensuring in maintaining the constitutional mandate of a minimum of 60% forest cover all times. In addition, the biomass and carbon estimates provided through the NFI shall help us monitoring Bhutan's carbon stock and understand sequestration potential of our forest in the face of climate change. As a major carbon sink for Bhutan, Forest plays a greater role in upholding national targets and international commitments of carbon neutral Bhutan. Up-to date information on forest cover, carbon stock and the carbon sequestration capacity not only helps in better planning developmental activities but also helps in achieving constitutional mandate of 60% and Bhutan's commitment of remaining carbon neutral for all times to come.

Therefore, I would like to congratulate Director Lobzang and his team in Department of Forest and Park Services to completing the fieldwork and publication of the two volumes of the NFI report, which shall serve as basis for sustainable forest management and

Finally, I hope the information in the NFI reports shall serve useful for foresters, environmentalist, researchers, bureaucrats and policy makers both within and outside the Ministry, in planning for a happy and a developed Bhutan.

Tashi Delek

Karma Tshering

FOREWORD

དཔལ་ལྡན་འབྲུག་གཞུང་། ནུས་ཤུགས་དང་རང་བཞིན་ཐོན་སྐྱེད་ལྷན་ཁག།
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ROYAL GOVERNMENT OF BHUTAN
MINISTRY OF ENERGY AND NATURAL RESOURCES
DEPARTMENT OF FORESTS AND PARK SERVICES
THIMPHU

DIRECTOR

I am glad and proud to be part of the two consecutive National Forest Inventory (NFI); the 1st NFI (2012-2015/2018) and the current NFI (2nd National Forest Inventory). As the principal coordinator during the 1st NFI, I spearheaded the fieldwork and ensured completion of the NFI. The NFI was the first field-based inventory after Pre-Investment Survey (PIS) carried out with the help of Government of India from 1974-79. The 1st NFI collected data from 1,685 accessible cluster plots from the total 2,424 CP and helped establish the baseline data for future monitoring and measurement purposes.

Realizing the importance of periodic National Forest Inventory, the Royal Government of Bhutan embarked on the 2nd NFI and I have the privilege of being the overall In-charge ensuring smooth flow of the field work and report preparation. The fieldwork for the 2nd NFI was conducted from 2021-2022 and the data analysis and report preparation from 2022-2023 FY. The 2nd NFI re-measure the permanent sample plots to monitor change (any disturbances, land use change, etc.) and growth (how individual trees are growing, dbh, height). This is important to ensure that the constitutional mandate of a minimum of 60 % Forest Cover for all times to come and to fulfil the other national and international commitments. This also guides the Department and the Ministry in formulation of Plans and Policies for a developed Bhutan.

The NFI is a challenging and arduous task especially for a mountainous country like ours and I applaud everyone involved in the NFI; especially the field crew who have given their best in collecting the data. Everyone involved in the fieldwork played an important role; from the data managers to the Chief Forestry Officers of the field offices. The information collected shall remain as an important source of data for better understanding our forest

The NFI would have been difficult without the team at the then Forest Resources Management Division, now housed in the Forest Monitoring and Information Division (FMID). Coordinating and ensuring the smooth implementation of the NFI fieldwork during the COVID-19 pandemic is no easy feat. Further, it is a proud moment for the Department that the data compilation and analysis have been done solely with inbuilt capacities. For that, I applaud the team in FMID for giving in their best in coming out with a comprehensive report; National Forest Inventory Volume I : State of Forest Report and National Forest Inventory Volume II : State of Forest Carbon Report

Tashi Delek

Lobzang Dorji

ACKNOWLEDGEMENT

The conduct of National Forest Inventory is very difficult especially in a country like ours, where resources are scarce, both in terms of human resource and financial resources. The topography and the terrain made it even more difficult for the NFI crews to traverse from a plot to another. In addition to that, the field work was conducted during the covid-19 pandemic amidst the lockdown and the anxiety arising from the spread of the pandemic. Therefore, it required combined efforts of many contributors, who helped in the implementation of the field work and publication of the National Forest Inventory Volume I: State of Forest Report and the National Forest Inventory Volume II: State of Forest Carbon Report.

The conduct of NFI at such times would have been difficult without the unwavering support of the Hon'ble Director. Therefore, we would like to thank the Hon'ble Director, Department of Forest and Park Services, for his continuous support through the NFI in ensuring we have all the resources and facilities for the conduct of the NFI in place.

The NFI crew members deserves all the accolades for having done a great job in collecting quality data in a span of a year (2021-2022). Despite the challenges of the pandemic and erratic weather conditions that year, the NFI crews were enthusiastic and showed great determination and will power in data collection, for which, we will always be grateful for. The data managers and the Chief Forestry Officer in all field offices also helped in ensure quality data collection and smooth implementation of the field work.

In addition, quality assurance and quality control (QAQC) are key to quality data collection and required combined effort of all the functional Divisions. Therefore, we would like to specially mention to Mr. Dawa Zangpo, Dy.CFO, FMID, Mr. Tashi Norbu Waiba, Dy. CFO, FRPMD, Mr. Lhab Tshering, Sr. CFO, FRPMD, Mr. Ugyen Tshering, Sr. Forest Ranger I, Wangdue Forest Division, Mr. Nim Dorji, Driver, DoFPS, Mr. Karma Wangdi, Driver DoFPS, Mr. Jamphel Lhendup, Driver, NCD and Mr. Jamtsho Cheda, Driver, FMID for joining the QAQC team and being an important part of the improving data quality in the NFI.

The Above-ground Biomass of trees and saplings are estimated using allometric biomass equations and the Below-ground Biomass is accordingly estimated using the root shoot ratio. The biomass team led by Mr. Yograj Chettri and other colleagues in UWIFoRT developed 21 new allometric equations after the 1st NFI helping immensely in the estimation of biomass carbon. Today, 35 species specific and 2 general allometric equations are available and were used for biomass estimation. These may have improved the estimation of tree biomass. In addition, the team in the tree laboratory including Mr. Dorji Dukpa, Mr. Chngdu Tshering, Mr. Kuenzang Tshering and Mr. Dhan Bdr. Gurung showed great hard work and determination in the measurement of more than 4100 tree cores for estimating increment. Therefore, we are immensely grateful to M. Shacha Dorji, Dr. Kaka Tshering and others in UWIFoRT for their support to the NFI.

Estimation of total carbon would not have been possible without the support of the Soil Plant and Analytical Laboratory (SPAL), National Soil Service Centre of Department of Agriculture. Mr. Jamyang, Specialist and his team worked tirelessly in carrying out the laboratory analysis of the Soil and Understorey above ground biomass. Mr. Jamyang have provided continued support and guidance throughout the two NFIs, for which we are immensely grateful.

We would also like to thank the Royal Government of Bhutan, Bhutan for Life Project, the REDD Readiness Proposal Project under the Forest Carbon Partnership Facility (FCPF) of the World Bank and the GEF NAPA III-"Enhancing Sustainability and Climate Resilience of Forest and Agricultural Landscape and Community Livelihoods in Bhutan" Projects for the continued financial support at different stages of planning, training, implementation and preparation of NFI reports.

Further, we would like to thank other officials of the Department of Forests and Park Services; (i) Mr. Sonam Tobgay, CFO, FRPMD; (ii) Ms. Sonam Peldon, Principal Forestry Officer, FRPMD; (iii) Dr. Sangay, Principal Forestry Officer, UWIFoRT; (iv) Mr. Rixzin Wangchuk, Sr. Forestry Officer, FMID; and (v) Ms. Jamyang Choden, Sr. Forestry Officer, FMID for providing your valuable comments and proof reading the final draft of the document.

Lastly, we would like to thank all Chief Forestry Officers and staffs of the then Forest Resources Management Division for their continued support in completion of the fieldwork and publication of the Reports.

Forest Monitoring and Information Division

EXECUTIVE SUMMARY

Forest is a major carbon sink for Bhutan and plays a greater role in upholding national targets and international commitments. Bhutan's net sequestration was reported as 6.79 million tonnes of CO_2 in the first biennial update report (BUR) of Bhutan to United Nations Framework Convention on Climate Change (UNFCCC) in 2022. This shows Bhutan's achievement vis-à-vis the commitment to mitigate the impacts of climate change with action. It is, therefore, important to monitor the change in Forest cover and Forest carbon stock to uphold our commitment for climate action through a periodic National Forest Inventory (NFI) ,which provides essential data and information for forest management and climate change policy, planning and decision making. The 2nd NFI was built on the experience and learning from the 1st NFI and is expected to provide estimate on the biomass and Carbon; stock and increment over the years, besides the traditional Forest parameter of tree count, basal area, growing stock, etc. The findings of the NFI is published in two reports; (i) National Forest Inventory Volume I: State of Forest Report and (ii) National Forest Inventory Volume II: State of Forest Carbon Report

Some of the major assumptions of the National Forest Inventory Volume II: State of Forest Carbon Report are:

1. The NFI design has 2,424 Cluster Plot (CP) laid at 4 km x 4 km grid across the country, from which 20 % of the plot are randomly selected as *"Carbon plot"* for the collection of understorey shrub, herb, litter and soil samples.
2. Only 1,969 CP were accessible for data collection and accordingly, understorey data collection could only be done for 354 CP.
3. Forest is defined as any land area with trees spanning more than 0.5 ha with trees higher than 5 m height and canopy cover of more than 10%. Forests is not restricted to the State Reserved Forest Land and includes all types of land meeting the minimum threshold of the Forest definition irrespective of their ownership, land use and legal status except land under permanent agriculture or horticulture crops.
4. Biomass and carbon for five carbon pools; (i) AGB, (ii) BGB; (iii) CWD; (iv) Litter and (v) SOC is estimated. The sixth carbon pool, harvested wood product (HWP) is not considered as it is beyond the scope of the NFI.
5. Below-ground biomass (BGB) is estimated using the root to shoot ratio.
6. Biomass is converted into carbon using Carbon Fraction (CF) of 0.47

Some of the key findings for the Biomass and Carbon estimation are:

Biomass and Carbon

- Bhutan's Forest constitute 86 % of the total carbon stock of Bhutan with 523.87 million tonnes of carbon with a carbon density of 195.73 tonnes ha^{-1}.
- The total carbon stock of Bhutan is 609.01 million tonnes which translates to a carbon density of 268.94 tonnes ha^{-1}. This includes carbon in non-Forest areas.
- The total Carbon stock is the summation of biomass carbon and soil organic carbon (SOC). These includes a total biomass carbon of 341.54 million tonnes of carbon and a SOC of 182.33 million tonnes, which translates to 127.61 tonnes ha^{-1} of biomass carbon and 68.12 tonnes ha^{-1} of SOC.

- The above-ground Biomass (AGB) constitutes 47 % of the total carbon stock, and the total AGB is 523.41 million tonnes with 91.91 tonnes ha^{-1}. The total AGB Carbon is 246 million tonnes which translates to 91.91 tonnes ha^{-1}.

Dzongkhag

- The total carbon stock ranges from 7.17 million tonnes in Tsirang Dzongkhag to 53.86 million tonnes in Wangdue Phodrang Dzongkhag.
- The greatest Carbon density is estimated in Haa Dzongkhag at 255.1 tonnes ha^{-1} while Samdrup Jongkhar Dzongkhag has the smallest estimate at 121.31 tonnes ha^{-1}.
- The SOC density is smallest in Samdrup Jongkhar Dzongkhag with 33.35 tonnes ha^{-1} and greatest in Haa Dzongkhag with SOC density of 108.81 tonnes ha^{-1}.

Forest Type

- Average carbon density in Coniferous Forest (210.08 tonnes ha^{-1}) is greater than the Broadleaved Forest (188.68 tonnes ha^{-1})
- Total carbon stock in Broadleaved Forest (343.32 million tonnes) is greater than the total carbon stock in Coniferous Forests (180.01 million tonnes)
- The total carbon stock is greatest in Cool Broadleaved Forest with 189.15 million tonnes and smallest in Chir Pine Forest with 7.49 million tonnes.
- The carbon density is smallest in Chir Pine Forest at 95.47 tonnes ha^{-1} while Hemlock Forest has the greatest estimate at 263.21 tonnes ha^{-1}.
- The SOC density is greatest in Fir Forest (95.40 tonnes ha^{-1}) and smallest in subtropical Forest (34.66 tonnes ha-[1]).

Elevation

- Biomass carbon density is greatest in elevation range of 2000-3000 *m.a.s.l* with 163.07 tonnes ha^{-1} and smallest in elevation above 4000 *m.a.s.l* at 45.94 tonnes ha^{-1}.
- SOC carbon density is greatest in the elevation range of 3000-4000 *m.a.s.l* with 92.07 tonnes ha^{-1}.

Biomass Growth and Carbon Sequestration

- Biomass growth in Forest is 2.43 tonnes ha^{-1} yr^{-1} which is equivalent to 1.14 tonnes ha^{-1} yr^{-1} of carbon
- Biomass increment range from 0.98 tonnes ha^{-1} yr^{-1} to 5.29 tonnes ha^{-1} yr^{-1} and carbon incr -ement range from 0.46 tonnes ha^{-1} yr^{-1} to 2.46 tonnes ha^{-1} yr^{-1}.
- Pemagatshel Dzongkhag saw the greatest biomass and carbon increment in last five years while Gasa Dzongkhag recorded the smallest biomass increment
- The biomass and carbon increment in Broadleaved Forests is 2.55 tonnes ha^{-1} yr^{-1} and 1.20 tonnes ha^{-1} yr^{-1} which is greater than biomass (2.12 tonnes ha^{-1} yr^{-1}) and carbon (1.00 tonnes ha^{-1} yr^{-1}) in Coniferous Forests.
- Biomass increment range from 0.58 tonnes ha^{-1} yr^{-1} in Juniper Rhododendron Forests to 3.45 tonnes ha^{-1} yr^{-1} in Blue Pine Forests and carbon increment range from 0.27 tonnes ha^{-1} yr^{-1} to 2.46 tonnes ha^{-1} yr^{-1}.

- *Quercus spp.* has the greatest biomass and carbon increment with biomass and carbon growth of 0.238 tonnes ha^{-1} yr^{-1} and 0.112 tonnes ha^{-1} yr^{-1} respectively.
- The total carbon sequestration potential of Forests is 11 million tonnes of CO_2 per annum in the form of aboveground biomass accumulation.
- Broadleaved Forest sequesters (4.4 tCO_2 yr^{-1}) more carbon than the Coniferous Forest (3.66 tCO_2 yr^{-1})

ACRONYM AND ABBREVIATION

AGB	Above-ground carbon
ba	Basal area
BGB	Below-ground biomass
BPFr	Blue Pine Forest
BUR	Biennial update report
CBFr	Cool Broadleaved Forest
CF	Carbon Fraction
CP	Cluster Plot
CPFr	Chir Pine Forests
CWD	Coarse woody debris
DBH	Diameter at Breast Height
DBH	Diameter at Breast Height
DOM	Dead organic matter
E	East
EoFr	Evergreen Oak Forests
FIFr	Fir Forests
FREL	Forest Reference Emission Level
FRL	Forest Reference Level
GHG	greenhouse gas
HMFr	Hemlock Forests
HWP	Harvested wood product
JRFr	Juniper Rhododendron Forests
km	Kilometer
L	Elbow
m	Meter
N	North
NDC	Nationally Determined Contribution
NRDCL	Natural Resources Development Corporation Limited
OC	organic carbon content
SOC	Soil Organic Carbon
SPAL	Soil Plant and Analytical Laboratory
SPFr	Spruce Forests
SRF	State Reserve Forest
STFr	Subtropical Forests
TNC	Third National Communication
UNFCCC	United Nations Framework Convention on Climate Change
WBFr	Warm Broadleaved Forest

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1 INTRODUCTION

1.1 Background

The main objective of Sustainable Forest Management (SFM) is to ensure that the demand for Forest produce is met sustainably through the application of principles of Sustainable Development. This requires sound Forest management techniques and effective monitoring systems to ensure that the resources are managed sustainably. Further, with the increasing threat from climate change, the role of SFM and monitoring of Forest resources has become even more important.

Forests play an important role in climate change mitigation and is widely recognized as a nature-based solution. Thus, the monitoring of Forest carbon stocks has become a critical activity not only for assessing Forest resources but also for assessment of other functions such as determining the primary productivity of our Forests, climate change mitigation potential and assisting in policy formulation & decision-making for Forest management and utilization.

1.2 Scope

The NFI provide estimates of the Forest growing stock, biomass & carbon stocks, species diversity and increment in addition to providing a comprehensive information on the ecological condition and biodiversity distribution of the country's Forests. The estimates generated from data analysis are grouped together and shall be published in two reports; (i) National Forest Inventory Volume I: State of Forest Report and (ii) National Forest Inventory Volume II: State of Forest Carbon Report.

This is the second part of the NFI report; the National Forest Inventory Volume II: State of Forest Carbon Report and shall hereafter be referred to as the report.

This report provides biomass and carbon estimates for Bhutan's Forest:

1. **Biomass and Carbon Estimates by Different Carbon Pool**
    - i. Above Ground Biomass and Carbon (Trees, Saplings, Shrubs and Herbs)
    - ii. Below Ground Biomass and Carbon (Trees and Saplings)
    - iii. Dead Organic Matter (Coarse Woody Debris and Litter)
    - iv. Soil Organic Carbon (SOC)
2. **Biomass and Carbon Estimates by Different Categories**
    - i. Dzongkhag
    - ii. Forest Type
    - iii. Elevation
    - iv. Diameter Class
    - v. Height Class
    - vi. Species

3. Biomass Growth and Carbon Sequestration
   - i. Forest and Non-Forest
   - ii. Dzongkhag
   - iii. Forest type
   - iv. Elevation

1.3 Carbon Stock Assessment in Bhutan

Bhutan, in 2009, committed to remain carbon neutral for all times to come, which was further reaffirmed in the first and second Nationally Determined Contribution (NDC) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in 2016 and 2020. Today, Bhutan is one of the few Carbon negative countries in the World. Carbon stock and net sequestration of Bhutan's Forest needs to be estimated to uphold the national priorities and international commitments. It is recommended to use country-specific data for more accurate estimates, otherwise, default IPCC could also be used.

While Forest Management inventories in terms of national level surveys, such as the Pre-Investment Survey (PIS) (1974 to 1979) and other management level inventories, date back to the 1960s and 1970s, these inventories mainly focused on the estimation of the extent of Forest and the total growing stock of our Forests. Carbon stock assessment was not reported then, which has gained importance today, given the role of Forests in climate change mitigation and adaptation, besides the fulfillment of national and international commitments.

Therefore, the Department embarked on the 1st NFI; the fieldwork for which was done in 2012-2015. The 1st NFI provided the baseline information on biomass and carbon stock of Bhutan's Forests. The total carbon stock of our Forests (including SOC) was estimated to be around 645.12 million tonnes with a carbon density of 234.85 tonnes ha^{-1}. In addition, the total biomass of our Forests was 972.91 million tonnes which was equivalent to 457.27 million tonnes of carbon. Bhutan's Average Biomass Stock is 170.77 ± 5.15% tonnes ha^{-1}.

Table 1.1 Biomass and Carbon estimate from the 1st NFI (DoFPS, 2020; FRMD, 2018b)

Carbon pools	Carbon Pool component	Biomass (tonnes ha^{-1})	Carbon (tonnes ha^{-1})	Total Biomass (million tonnes)	Total carbon (million tonnes)	Margin of Error %
Above ground Biomass (AGB)	Trees	241 ± 14	113.74	657.15	308.86	6
	Shrubs	1.61 ± 0.27	0.7567	4.72	2.22	16
	Herbs	0.71 ± 0.15	0.3337	2.07	0.97	21
	Sapling	26 ± 10	12.22	72.31	33.99	39
Below ground Biomass (BGB)	Tree Roots	64.46 ± 5	30.3	157.41	73.98	5.419
	Sapling roots	8.88 ± 3.8	4.1736	22.08	10.38	34.45
Litter	Litter	13.25 ± 2	6.2275	39.03	18.34	16
Dead wood	Coarse woody Debris	6.44 ± 3	3.0268	18.14	8.53	41

Soil	Soil (0-30cm depth)		64.07 ± 2		187.85	8
Total Forest Carbon Stock					645.12	4

The NFI report provided country-specific data and information for the development of the National Forest Reference Emission Level (FREL) and/or the National Forest Reference Level (FRL); one of the four key REDD+ architecture required for REDD+ implementing countries. Accordingly, Bhutan's FREL proposed to maintain emissions of 0.55 million tonnes of CO_2e per year in the Forest sector. Further, FRL for Bhutan has proposed to maintain net sequestration of 8.76 million tonnes of CO_2e per year (DoFPS, 2020). The data from the NFI also complemented the national greenhouse gas (GHG) inventory which is an important component of the national communication and biennial update report (BUR) to the UNFCCC. In 2020, Bhutan submitted the third national communication (TNC) to the UNFCCC using country-specific data, wherein the inventory reported net sequestration of 5.57 million tonnes of CO_2 for the inventory year 2015 (NEC, 2020) including emissions from all sectors. Further, NFI data was used in the development and preparation of the first BUR of Bhutan to UNFCCC in 2022 and reported a net sequestration of 6.79 million tonnes of CO_2 (NEC, 2022) for the inventory year 2020. NFI data also played an important role in the development and preparation of the second NDC under the Paris Agreement and provided country-specific data for setting targets for reducing or maintaining GHG emissions in the forestry sector. The second NDC reiterated our commitment to remain carbon neutral for all times to come therefore, the NFI is an important source of data for tracking our progress on GHG emissions from forestry and other land use, as well as other sectors such as energy and transport, waste, agriculture including livestock, industries (industrial product and product use).

The 2nd NFI was envisaged to monitor change in biomass and carbon over the years wherein the biomass and carbon estimation remain important components of the NFI design. The main objective of the 2nd NFI is to provide updated information on Forest biomass and carbon stock, and, to assess the biomass / carbon accumulation in the Forest, which will be useful for sustainable Forest management and utilization, Forest health monitoring, National greenhouse gas inventory and other international reporting requirements; and to assess the potential of our Forest for carbon trading under Paris Agreement/Voluntary carbon markets

This report shall discuss the: (i) Forest biomass and carbon stock; (ii) biomass and carbon increments, while discussing the trends and changes independently, as well as in relation to the 1st NFI.

METHODOLOGY

2 METHODOLOGY

2.1 Field Methodology

2.1.1 Sampling and Plot Design

Biomass and Carbon are estimated for different carbon pools which are summed up to estimate the total Biomass and Carbon stock and the per hectare estimates. Tree and sapling data are collected extensively by following the sampling design adopted in general for the NFI. There are 2,424 cluster plots (CP) for the NFI, laid at a 4 km x 4 km grid, spread across the country. In addition, 20 % of the CP are selected randomly for the collection of above-ground understorey, litter and soil samples for estimation of carbon. These plots are commonly referred to as *"carbon plots"*. Figure 2.1 shows the sampling design for the NFI, along with the accessible *"carbon plots"*.

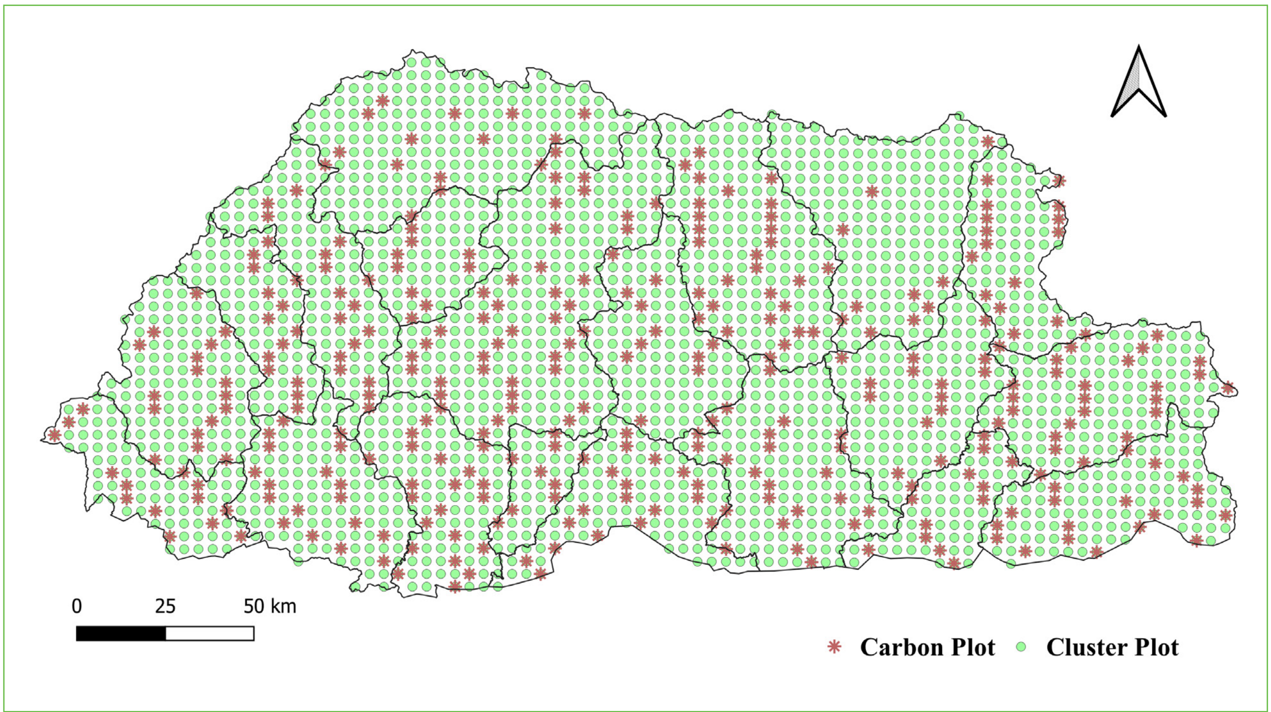

Figure 2.1 NFI Sampling design with "Carbon plots"

Each CP consists of 3 circular plots of 12.62 m radius placed on an "L" shaped transect 50 m apart and are referred to as the Elbow (L), North (N) and East (E) plots. As discussed, Tree and Sapling data used for the estimation of Above-ground Biomass (AGB) are collected from all the plots in these 2,424 CP. Further, the Coarse Woody Debris (CWD) is collected along the 50 m transect from L to N and L to E plot (Figure 2.2) in all CP.

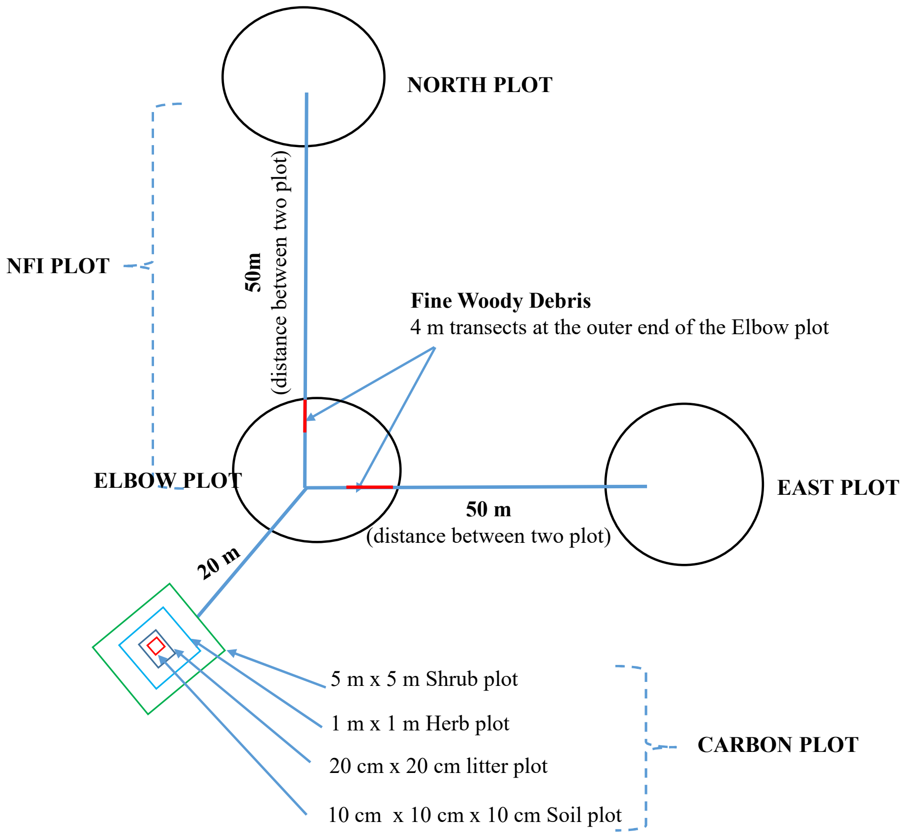

Figure 2.2 NFI Plot design

The *"carbon plots"* are laid 20 m South-West from the "L" plot, at an azimuth of 225°, wherein a 5 m x 5 m square plot is laid out for destructive sampling of the shrubs. Herb samples are collected destructively from a 1 m x 1 m square plot laid within the shrub plot. Similarly, litter samples are collected from a 30 cm x 30 cm plot laid inside the herb plot and soil samples are collected using 10 cm x 10 cm soil sampling frame laid inside the litter sample plot up to 30 cm depth in three different layers of 0-10 cm, 10-20 cm and 20-30 cm (DoFPS, 2021b; FRMD, 2020).

2.1.2 Data Collection

NFI data collection is done using the Open Foris Collect Mobile application installed on handheld Android device. The data collection modality and procedure are discussed in the National Forest Inventory Volume I: State of Forest Report 2023. However, some of the important considerations during data collection for biomass and carbon estimation are:

- Tree and sapling data are collected from all CP. All tree species with a Diameter at Breast Height (DBH) equal to and above 10 cm are considered as "Tree" while tree species with DBH equal to and above 5 cm and below 10 cm are considered "Sapling";
- Below-ground biomass (BGB) is estimated using the commonly used root-to-shoot ratio (Mokany et al., 2006; IPCC, 2006);
- The shrub, herb, litter, and soil are collected in the *"carbon plot"* and sent to the Soil Plant and Analytical Laboratory (SPAL), National Soil Services Center under the Department of Agriculture, Ministry of Agriculture and Livestock for biomass analysis;

- Soil samples are collected up to 30 cm depth in three different layers of 0-10 cm, 10-20 cm and 20-30 cm;
- All downed and dead tree boles, large branches and other woody pieces that are severed from their original source of growth are considered CWD. However, only those CWD with a length of at least a meter or greater, and whose (i) central longitudinal axis of CWD intersect with transect, (ii) have a minimum of 10 cm diameter at the point of intersection with transect; and are not decayed to the point of having no structural integrity, are considered and taken for measurement (DoFPS, 2021b; FRMD, 2020);
- The decay class reduction factor of the CWD has been adopted from Waddell, 2002; Woodall & Monleon, 2007 for estimation of biomass;
- Tree cores are collected from 20 % of the cluster plots from plots designated as understorey carbon plots. The core sample are collected using a *Haglof* increment borer; a minimum core length of 15 cm for larger trees and a complete core for smaller diameter trees were collected, stored in plastic straws, and sent to the tree laboratory, Ugyen Wangchuck Institute for Forest Research and Training (UWIFoRT) for drying, examination and measurement.

The detailed data collection protocol and implementation modality of the NFI fieldwork is explained in the Field Manual: *National Forest Inventory of Bhutan 2020*[1], *National Forest Inventory Data Management Protocol, 2020*[2] *and Implementation Modality for NFI of Bhutan 2021*[3].

2.2 Estimation Method

The total carbon stock density of Forest is the sum of the carbon stock density of all carbon pools as described in equation (2.1):

$$C_{ts} = AGB_{tC} + BGB_{tC} + AGB_{sapC} + BGB_{sapC} + AGB_{shrubC} + AGB_{herbC} + CWD_C + L_C + SOC \quad \textbf{(2.1)}$$

Where,

C_{ts} = total carbon stock (tC ha^{-1});

AGB_{tc} = Tree AGB carbon stock (tC ha^{-1});

BGB_{tC} = Tree BGB carbon stock (tC ha^{-1});

AGB_{sapC} = Sapling AGB carbon stock (tC ha^{-1});

BGB_{sapC} = Sapling BGB carbon stock (tC ha^{-1});

AGB_{shrubC} = Shrub AGB carbon stock (tC ha^{-1});

AGB_{herbC} = Herb AGB carbon stock (tC ha^{-1});

CWD_C = CWD carbon stock (tC ha^{-1});

L_C = Litter carbon stock (tC ha^{-1}); and

SOC = Soil organic carbon stock (tC ha^{-1})

The total carbon stock (million tonnes) is also estimated using the same equation, and carbon stock is a product of carbon density and area of the stratum. The biomass and carbon estimation methods adopted in 2nd NFI for different carbon pools are described in the following sections.

[1] https://www.dofps.gov.bt/download/4268/?tmstv=1686804506
[2] https://www.dofps.gov.bt/download/4272/?tmstv=1686804506
[3] https://www.dofps.gov.bt/download/4276/?tmstv=1686804506

2.2.1 Biomass Estimation

Biomass is estimated for the four (4) carbon pools; (i) the Above-ground Biomass (AGB); (ii) Below-ground Biomass (BGB); (iii) Coarse Woody Debris (CWD); and (iv) Litter. These are then converted into carbon using carbon fraction. The estimations of biomass for different pools are discussed herein.

2.2.1.1 Above-Ground Biomass

Trees and Sapling

The AGB pool consists of woody and herbaceous plants including leaves, barks, seeds and stems above the soil (IPCC, 2006). The AGB of trees (DBH =>10cm) and saplings (10>DBH >=5cm) are estimated using 35 species-specific and 2 general allometric biomass equations. The general form of allometric equations is described in equation (2.2), which is a linear interpolation of the cubic spline function of basal area (ba) as a predictor variable.

$$AGB = \beta_0 + \beta_1 ba + \beta_2 X_2$$

(2.2)

Where,

AGB = aboveground biomass, (kg);
ba = basal area (m^2);
β_0, β_1, β_2 = coefficients; and
X_2 = g(ba) .

The X_2 corresponds to spline function of ba as follows:

$$X_2 = \mathrm{g(ba)} = (ba - t1)_+^3 - (ba - t2)_+^3 \frac{(t3 - t1)}{(t3 - t2)} + (ba - t3)_+^3 \frac{(t2 - t1)}{(t3 - t2)}$$

(2.3)

and the value of the each component of equation (2.3) is computed using the knot values with equation (2.4), (2.5), and (2.6);

$$(ba - t1)_+^3 = (X - t1)_+^3, \text{ if ba} > \text{t1 and } (ba - t1)_+^3 = 0, \text{ if ba} < \text{t1}$$

(2.4)

$$(ba - t2)_+^3 = (X - t2)_+^3, if\ ba > t2, and\ (ba - t2)_+^3 = 0, if\ ba < t2$$

(2.5)

$$(ba - t3)_+^3 = (X - t3)_+^3, \text{ if ba} > \text{t3, and } (ba - t3)_+^3 = 0, \text{ if ba} < \text{t3}$$

(2.6)

t_1, t_2 and t_3 for the above models are 10^{th}, 50^{th} and 90^{th} percentiles of ba called knots.

The list of 35 species specific and two (2) general allometric equations used for estimation of biomass is provided in Annexure 9.1.

Shrubs and Herbs

Understorey AGB consists of biomass stored in shrubs and herbs. 485 CP were designated for the destructive sampling of shrubs and herbs during the field survey. However, data collection could be done only in 354 CP because of the inaccessibility of the plots.

The biomass of the destructively sampled shrubs and herbs are processed following the procedure described in *"Laboratory manual for aboveground understory and soil organic carbon analysis"* (FRMD, 2018a) and are estimated using the equation (2.7).

$$AGB_{s,h} = \frac{W_f}{A} \times \frac{W_{sub,dry}}{W_{sub,wet}} \times \frac{1}{1000,000}$$

(2.7)

Where,

$AGB_{s.h}$ = is aboveground biomass of shrub, herb (t ha^{-1});

A = is plot area for shrub or herb sample (ha);

W_f = fresh weight of the shrub, herb sample as measured in the field(g);

$W_{sub,dry}$ = Oven dry weight of the subsample, measured in the lab (g); and

$W_{sub,wet}$ = Wet weight of the subsample (g).

2.2.1.2 Below-Ground Biomass

The BGB consists of all fine and coarse roots and therefore, the measurement of the BGB is time consuming (Marziliano et al., 2015; Mokany et al., 2006) and there is no consensus on the most suitable method for estimation of below ground biomass (Addo-Danso et al., 2016). However, root-to-shoot ratio is commonly adopted to estimate the belowground biomass (IPCC, 2006; Mokany et al., 2006). The BGB is estimated for a plot and not at the individual tree level using the equation (2.8) (Mokany et al., 2006).

$$BGB_p = 0.489 \times AGB_p^{0.89}$$

(2.8)

Where,

BGB_p = below ground biomass at plot level, (t ha^{-1}); and

AGB_p = aboveground biomass at plot level, (t ha^{-1})

2.2.1.3 Coarse Woody Debris

Dead organic matter (DOM) comprises of two carbon pools of dead wood and litter (IPCC, 2006). The dead wood in this report refers to the biomass/carbon of the CWD which are sampled in the two 50 m transects using the line intersect sampling method, where any downed wood intersecting the transect are enumerated. For each downed wood, diameter at the point of intersection, small end, large end, length of the intersection, total length and the width of downed wood are measured and recorded (FRMD, 2020). The CWD is classified into 5 decay classes based on the state of the decay of the wood, and is applied to the biomass estimation to account for decrease in wood density (Russell et al., 2013; Waddell, 2002). The volume of individual coarse woody debris is estimated using Smalian's volume formula (equation (2.9) (Baker & Chao, 2011; Waddell, 2002)

$$CWD_v = \frac{\pi \times (D_s^2 + D_L^2 \times l}{8 \times 10000}$$

(2.9)

Where,

CWD_v = volume of CWD in m^3;

D_s = diameter at small end in cm;

D_L = diameter at large end in cm; and,

l = length of the CWD in m.

The CWD volume is converted into per unit area estimate of volume using the modified DeVries' per unit formula (equation (2.10) ((Waddell, 2002)) as applied in the Forest Inventory and Analysis program of the United States for individual logs.

$$CWD_{vha} = \frac{\pi}{2L} \times \frac{CWD_v}{l} \times f$$

(2.10)

Where,

CWD_{vha} = volume per ha of individual piece of CWD (m^3 ha^{-1});

L = length of transect (m);

l = length of the CWD (m); and,

f = conversion factor for ha and it is constant of 10000 m^2ha^{-1}.

Further, the CWD volume per unit area is converted into biomass using the equation (2.11)

$$CWD_b = CWD_{vha} \times WD \times DCR$$

(2.11)

Where,

CWD_b = is CWD biomass (t ha^{-1});

WD = is wood density (t m^{-3}) (Table 2.1(FRMD, 2020); and,

DCR = is decay class reduction factor.

Table 2.1 shows the decay reduction factor for different decay classes and is reproduced from the *"Sampling Protocol, Estimation, and Analysis Procedures for the Down Woody Materials Indicator of the FIA Program"* (Woodall & Monleon, 2007) and *"Sampling coarse woody debris for multiple attributes in extensive resource inventories"* (Waddell, 2002)

Table 2.1 Decay class reduction factor for softwood and hardwood

Decay class /Species group	1	2	3	4	5	Wood density (t m^{-3})
Softwood	1	0.84	0.71	0.45	0.45	0.483
Hardwood	1	0.78	0.45	0.42	0.42	0.623

2.2.1.4 Litter Biomass

The litter samples are collected from every designated understory carbon plot as described earlier. The samples are collected using a 20 cm x 20 cm sampling frame, where all live vegetation is carefully removed and the entire volume of the litter within the sampling frame up to the mineral soil layer is carefully collected, weighed, marked with plot ID and send to the laboratory to determine its dry weight. The litter biomass was estimated using equation (2.7)[4] similar to the biomass of shrubs and herbs.

2.2.2 Biomass Carbon Estimation

In general, 50% of biomass is considered as carbon. However, a study in Bhutan found an average carbon content of 46.02 – 46.81 % biomass in five Forest types along the elevation gradient from Phuentsholing to Gedu-top (Tashi et al., 2017). This estimate is very close to the default IPCC carbon fraction of 47% for our region. The biomass in all biomass carbon pools is converted into carbon using the equation (2.12).

$$C_b = B \times CF \qquad \textbf{\textit{(2.12)}}$$

Where,

C_b = Carbon stock of biomass carbon pool (t ha^{-1});

B = Biomass stock of carbon pool (t ha^{-1}); and

CF = Carbon fraction (47%)

2.2.3 Soil Organic Carbon

The soil samples were analyzed in the laboratory for bulk density (g cm^{-3}) and estimation of Soil Organic Carbon (SOC) content for different layers of 0-10 cm, 10-20 cm and 20-30 cm. The soil samples were oven dried at a temperature of 105ºC until constant weight is achieved (FRMD, 2018a).

[4] Biomass of litter can also be estimated as dry weight of litter (g) x 100 / plot area (cm^2) (Pearson, Brown and Birdsey, 2007)) (t ha^{-1}) Forest carbon measurement guidelines

SOC was determined through the Walkley- Black method using the titrations for all samples except the soil samples with very high SOC content since the Walkley- Black method is unable to predict high carbon contents (De Vos et al., 2007). Soil samples with high organic carbon content (OC) are analyzed using the CHN Analyzer. OC is estimated using the standard Walkley-Black Method or automatically generated from CHN Analyzer. The bulk density and SOC are estimated using equation (2.13)(2.14) (FRMD, 2018a; Mandal et al., 2013; Pearson et al., 2007).

$$S_{bd} = \frac{S_{dry,weight}}{S_{vol}}$$

(2.13)

$$SOC_{ha} = SOC\ \% \times S_{bd} \times S_d$$

(2.14)

Where,

S_{bd} = bulk density of soil;

$S_{dry,}$ weight =dry weight of the soil sample;

S_{vol} = Volume of the soil/ sampling frame;

SOC_{ha} = Soil Organic carbon, (t ha^{-1}); and

SOC % = organic carbon content (%)

S_d = Thickness of horizon/ layer (cm).

2.3 Total Biomass and Carbon Estimate

The estimates are generated at 95% confidence interval at the national level based on the Forest and Non-Forest classification. The weighted mean of the attribute of interest (biomass, carbon) are estimated for each CP using the unbiased mean estimator as described in the National Forest Inventory Volume I: State of Forest Report. The mean of the stratum was estimated using equation (2.15).

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

(2.15)

Where,

$\bar{y}$ is the population mean of the parameter;

n is number of samples; and

y is the sample value.

The per ha estimates were then estimated using equation (2.16), (2.17), (2.18)

$$\bar{y}_{ha} = \bar{y}\, x\, A_{exf}$$

(2.16)

$$A_{exf} = \frac{1}{A_p}$$

(2.17)

$$A_p = \pi r^2$$

(2.18)

Where,

$\bar{y}_{ha}$ is the mean per ha of the parameter of interest;

A_{exf} is area expansion factor;

A_p is plot area, in ha; and

r is plot radius in m.

The standard deviation, standard error and confidence interval (95%) are estimated using the equation (2.19), (2.20) and (2.21) respectively. It is assumed that all Forest parameters are normally distributed across the space.

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{i=n}(y_i - \overline{y})^2}$$

(2.19)

$$SE = \frac{s}{\sqrt{n}}$$

(2.20)

$$CI = t * SE$$

(2.21)

Where,

s is sample standard deviation;

$\bar{y}$ is the population mean of the parameter;

n is number of samples;

y is the sample value;

SE is standard error of mean;

CI is confidence interval;

n is the number of samples; and

t is the t-value, function of the confidence level (t ≅ 2 for 95% confidence interval)

The total statistic of any domain is estimated by multiplying the mean value with the estimated value. Error was converted into percentages and combined uncertainties were calculated using the error propagation method defined in equation (2.22) (IPCC, 2006).

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \cdots + U_n^2}$$

(2.22)

Where,

U_{total} is the percentage of uncertainty in the product of the quantities; and

$U_{1,} U_n$ is the percentage uncertainties associated with each of the quantities.

The total carbon stock for different categories are obtained using the equation (2.1) and the uncertainty of the total carbon stock is estimated using the equation (2.23) (IPCC, 2006).

$$U_{total} = \frac{\sqrt{(x_1 \times u_1)^2 + (x_2 \times u_2)^2 + \cdots + (x_n \times u_n)^2}}{|x_1 + x_2 + \cdots + x_n|}$$

(2.23)

Where,

U_{total} = percentage of uncertainty in the sum of the quantities; and

x_1, u_n = the uncertain quantities and the percentage uncertainties associated with them

FOREST BIOMASS AND CARBON

3 FOREST BIOMASS AND CARBON

3.1 Background

Forest biomass encompasses all parts of the plant such as the branches, leaves, bark, trunk, needles, roots, etc., which can be converted to energy. Watson (2009) defines Forest biomass as *"organic matter resulting from primary production through photosynthesis minus consumption through respiration and harvest"*. Total biomass is estimated using the data collected through the NFI and biomass allometric equations. The biomass is then converted to biomass carbon by multiplying the biomass estimated by a Carbon Fraction (CF) of 0.47 (IPCC, 2006). In addition, carbon estimates from SOC are added to the Biomass carbon to estimate the total carbon stock of Bhutan's Forests.

For this report, biomass and carbon for five carbon pools; (i) AGB, (ii) BGB; (iii) CWD; (iv) Litter and (v) SOC have been estimated. The sixth carbon pool, harvested wood product (HWP) has not been considered as it is beyond the scope of the NFI. The total carbon stock of Bhutan is 609.01 million tonnes which translates to a carbon density of 268.94 tonnes ha^{-1}. Table 3.1 shows the carbon density and total carbon stock in Forest and Non-Forest.

Table 3.1 Carbon estimate for Forest and Non-Forest

Land Class	Carbon (tonnes ha^{-1})	MoE (%)	Total Carbon (million tonnes)	MoE (%)
Forest	195.73	3.89	523.87	4.04
Non-Forest	73.22	12.68	85.15	12.77

Bhutan's Forest constitutes 86 % of the total carbon stock of Bhutan with 523.87 million tonnes of carbon with a carbon density of 195.73 tonnes ha^{-1}. Non-Forests have a comparatively less total carbon stock of 85.15 million tonnes. The distribution of the Forest carbon by different carbon pools is shown in Table 3.2 and the proportion of different carbon pools to the total carbon stock is shown in Figure 3.1.

Table 3.2 Biomass and Carbon estimate for Forest

Carbon Pool	Carbon Pool Constituents	Biomass				Carbon			
		Biomass (tonnes ha^{-1})	MoE (%)	Total (million tonnes)	MoE (%)	Carbon (tonnes ha^{-1})	MoE (%)	Total (million tonnes)	MoE (%)
AGB	Tree	190.31	6.02	509.39	6.31	89.45	6.02	239.41	6.31
	Sapling	3.44	41.47	9.21	41.51	1.62	41.47	4.33	41.51
	Shrub	1.38	21.11	3.68	21.19	0.65	21.11	1.73	21.19
	Herb	0.42	24.38	1.13	24.45	0.20	24.38	0.53	24.45
BGB	Tree	50.12	4.44	134.14	4.81	23.55	4.44	63.05	4.81
	Sapling	3.44	41.47	9.21	41.51	1.62	41.47	4.33	41.51

DOM	CWD	6.72	11.73	17.99	11.88	3.16	11.73	8.46	11.88
	Litter	15.67	13.91	41.94	14.04	7.37	13.91	19.71	14.03
Soil	Soil (0-30 cm depth)					68.12	7.44	182.33	7.67
Total Estimate						195.73	3.89	523.87	4.04

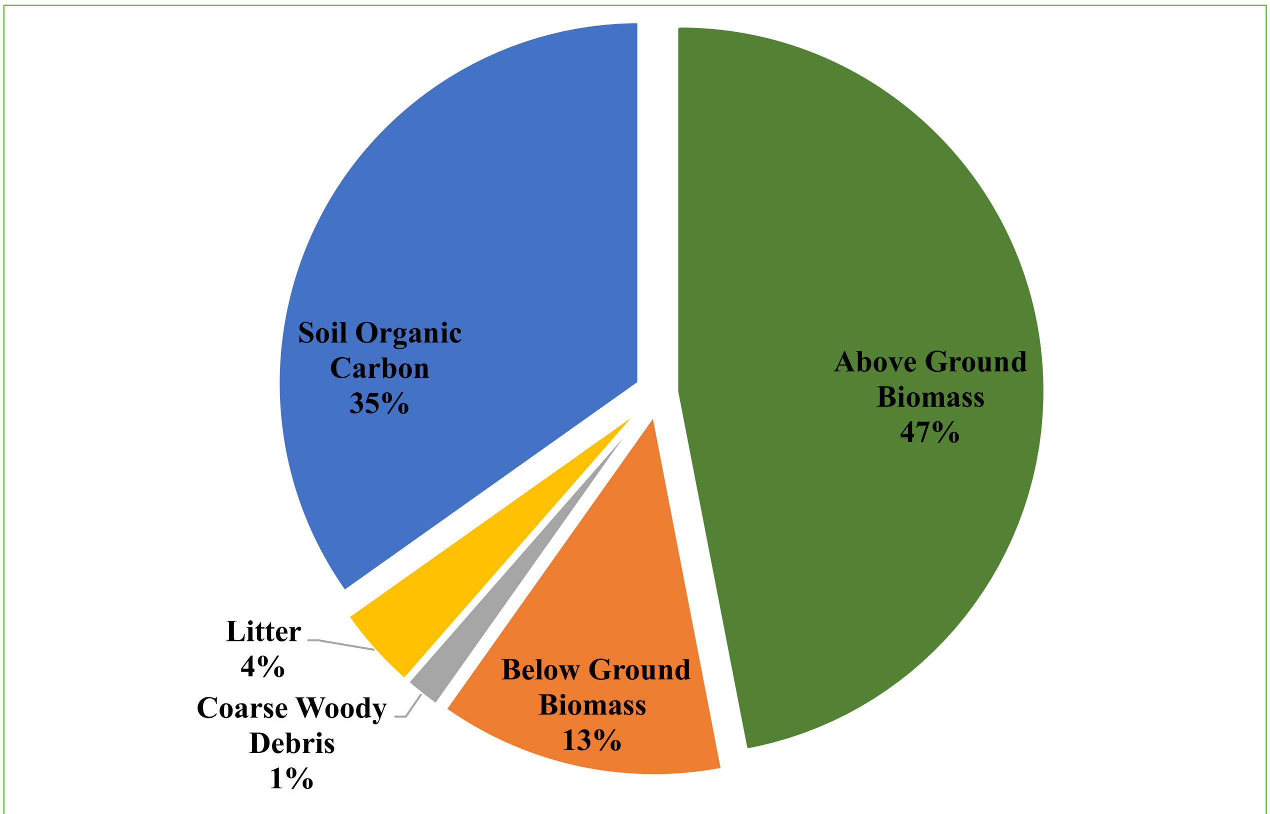

Figure 3.1 Distribution of total Carbon stock amongst the Different Carbon Pool

The AGB constitutes 47 % of the total carbon stock, followed by the SOC (35%). CWD has the least contribution at 1 % of the total carbon stock of Bhutan. These carbon pools and the pool components are described in detail in this chapter.

3.2 Biomass and Carbon by Different Carbon Pools

3.2.1 Above-ground Biomass (AGB) Carbon

The AGB Carbon is one of the major carbon pools and includes biomass of all trees, saplings, shrubs, and herbs. Biomass is estimated for all trees and saplings recorded in the NFI plots using estimation methods explained in Chapter 2: Methodology. Accordingly, the biomass and carbon content in all pool constituents are shown in Table 3.3.

Table 3.3 Biomass and Carbon stock in AGB Carbon Pool

Attribute	Density (tonnes ha^{-1})	MoE (%)	Total (million tonnes)	MoE (%)
AG Biomass	195.55	5.91	523.41	6.18
AGB Carbon	91.91	5.91	246.00	6.18

The total AGB Carbon is 246 million tonnes which translates to 91.91 tonnes ha^{-1}. The total AGB is 523.41 million tonnes with 195.55 tonnes ha^{-1}.

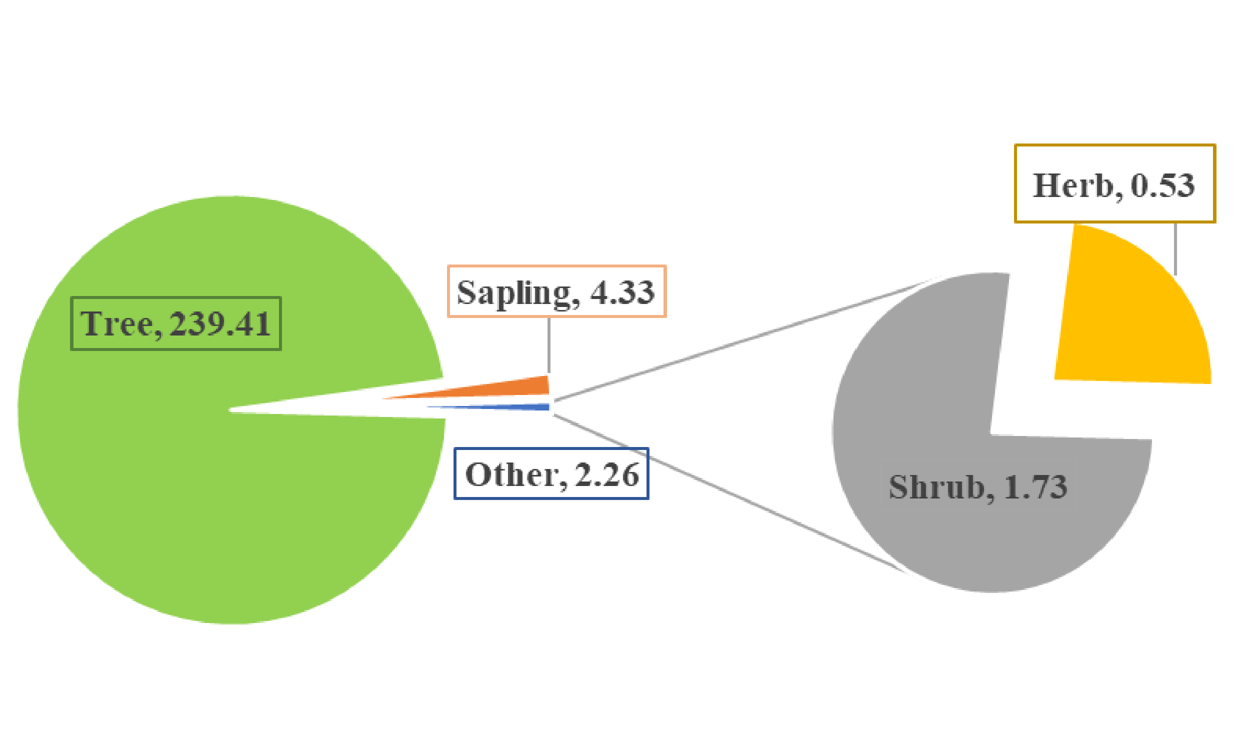

Figure 3.2 Proportion of carbon stock in different component of AGB

The estimates for the biomass carbon shall be explained by different components of the AGB. Since the biomass estimated for the different pool constituents are converted into carbon using the carbon fraction of 0.47, this report mainly focus and discuss Carbon stock and density.

3.2.1.1 Tree

Trees contribute 97 % of the total AGB Carbon stock of the Forest with 239.41 million tonnes and a density of 89.45 tonnes ha^{-1}. Broadleaved Forests constitute about 69 % of the total carbon from trees while Coniferous Forests constitute the remaining 31 %.

Table 3.4 Biomass and Carbon estimate for Tree

Attribute	Density (tonnes ha^{-1})				Total (million tonnes)			
	Estimate	MoE (%)	Lower Limit	Upper Limit	Estimate	MoE (%)	Lower Limit	Upper Limit
Biomass	190.31	6.02	178.85	201.78	509.39	6.31	477.27	541.5
Carbon	89.45	6.02	84.06	94.83	239.41	6.31	224.32	254.51

Species

Table 3.5 shows the biomass and carbon density of 31 species. These 31 species constitute about 69 % of the total carbon stock in the "Tree" component. The density estimates of the rest of the species are clubbed together under *"Others"* and accounts for 31 % of tree AGB.

Table 3.5 Total estimates for Biomass and Carbon by Species

Species	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Abies densa	70.73	14.94	60.16	81.29	33.24	14.94	28.28	38.21
Acer spp.	12.22	13.48	10.57	13.86	5.74	13.48	4.97	6.52
Ailanthus integrifolia	0.47	71.79	0.13	0.81	0.22	71.79	0.06	0.38
Alnus spp.	5.11	25.66	3.79	6.42	2.40	25.66	1.78	3.02
Aphanamixis polystachya	0.89	47.09	0.47	1.31	0.42	47.09	0.22	0.61
Beilschmiedia spp.	5.21	26.16	3.84	6.57	2.45	26.16	1.81	3.09
Betula spp.	9.01	17.04	7.48	10.55	4.24	17.04	3.51	4.96
Bombax ceiba	0.40	81.14	0.08	0.72	0.19	81.14	0.04	0.34
Castanopsis spp.	23.40	16.81	19.46	27.33	11.00	16.81	9.15	12.84
Cupressus spp.	1.42	169.84	(0.99)	3.83	0.67	169.84	(0.47)	1.80
Duabanga grandiflora	1.05	41.49	0.62	1.49	0.49	41.49	0.29	0.70
Engelhardtia spicata	4.31	25.45	3.21	5.40	2.02	25.45	1.51	2.54
Exbucklandia populnea	2.67	59.21	1.09	4.25	1.25	59.21	0.51	2.00
Juglans regia	0.62	54.78	0.28	0.96	0.29	54.78	0.13	0.45
Juniperus spp.	5.91	34.22	3.89	7.93	2.78	34.22	1.83	3.73
Larix griffithii	0.43	64.51	0.15	0.71	0.20	64.51	0.07	0.33
Magnolia spp.	5.44	27.16	3.96	6.92	2.56	27.16	1.86	3.25
Persea spp.	22.39	15.24	18.98	25.80	10.52	15.24	8.92	12.13
Phoebe goalparensis	0.42	74.14	0.11	0.74	0.20	74.14	0.05	0.35
Picea spinulosa	7.24	36.14	4.62	9.85	3.40	36.14	2.17	4.63
Pinus roxburghii	7.63	31.53	5.23	10.04	3.59	31.53	2.46	4.72
Pinus wallichiana	11.94	28.79	8.51	15.38	5.61	28.79	4.00	7.23
Quercus spp.	84.48	11.80	74.52	94.45	39.71	11.80	35.02	44.39
Rhododendron spp.	20.97	13.38	18.16	23.77	9.85	13.38	8.54	11.17
Schima wallichii	5.75	23.22	4.41	7.08	2.70	23.22	2.07	3.33
Sterculia villosa	0.87	49.31	0.44	1.30	0.41	49.31	0.21	0.61
Symplocos spp.	19.27	124.46	(4.71)	43.26	9.06	124.46	(2.22)	20.33
Taxus baccata	1.53	42.94	0.87	2.18	0.72	42.94	0.41	1.03
Terminalia myriocarpa	1.13	60.12	0.45	1.81	0.53	60.12	0.21	0.85
Tetrameles nudiflora	1.75	63.43	0.64	2.85	0.82	63.43	0.30	1.34
Tsuga dumosa	19.03	24.36	14.39	23.67	8.94	24.36	6.77	11.12
Others	155.63	6.37	145.72	165.55	73.15	6.37	68.49	77.81

Quercus spp. has the greatest carbon content with 39.71 million tonnes followed by *Abies densa* (fir) with 33.24 million tonnes. From the species reported, *Bombax ceiba* and *Phoebe goalparensis* have the least carbon with 0.18 and 0.19 million tonnes respectively. Figure 3.3 shows the biomass and carbon density of the 31 species reported in the report.

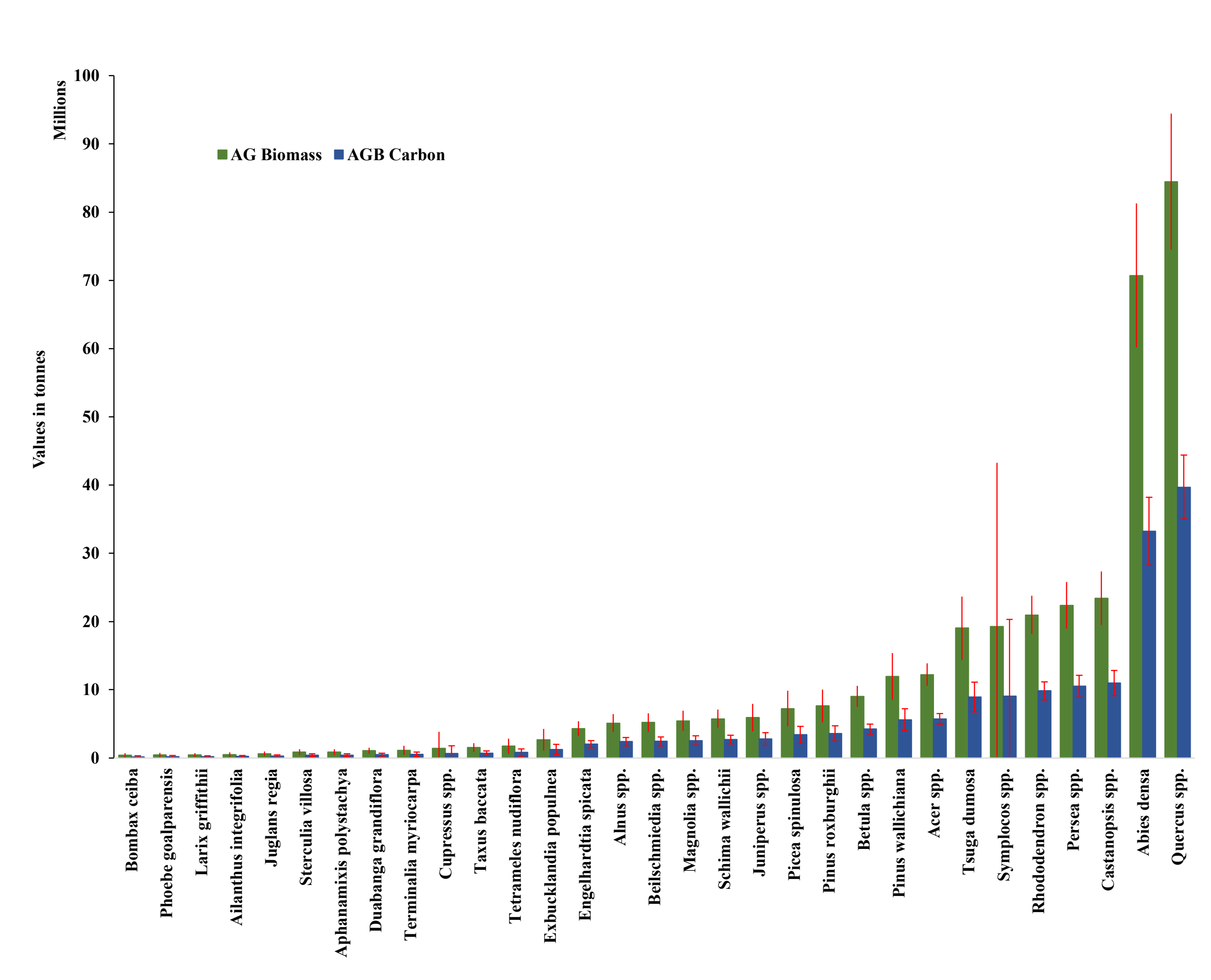

Figure 3.3 Biomass and Carbon density estimate by Species

DBH Class

The Biomass and Carbon across different DBH class is shown in Table 3.6. For the purpose of carbon estimation, DBH is divided into 19 DBH classes; the smallest DBH class is 10-20 cm while the largest is trees >= 190 cm.

Table 3.6 Biomass and carbon density by DBH Class

DBH Class (cm)	AGB (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
10-20	15.70	7.31	14.55	16.85	7.38	7.31	6.84	7.92
20-30	16.37	4.31	15.66	17.07	7.69	4.31	7.36	8.02
30-40	17.45	3.86	16.78	18.13	8.20	3.86	7.89	8.52

40-50	17.69	4.34	16.92	18.45	8.31	4.34	7.95	8.67
50-60	18.17	5.41	17.18	19.15	8.54	5.41	8.08	9.00
60-70	17.67	6.06	16.60	18.74	8.30	6.06	7.80	8.81
70-80	16.39	7.16	15.22	17.57	7.71	7.16	7.15	8.26
80-90	16.54	9.14	15.03	18.05	7.77	9.14	7.06	8.49
90-100	12.52	10.25	11.24	13.81	5.89	10.25	5.28	6.49
100-110	8.24	13.81	7.11	9.38	3.87	13.81	3.34	4.41
110-120	8.18	15.19	6.94	9.43	3.85	15.19	3.26	4.43
120-130	5.94	19.08	4.80	7.07	2.79	19.08	2.26	3.32
130-140	8.28	108.32	(0.69)	17.24	3.89	108.32	(0.32)	8.10
140-150	3.24	26.55	2.38	4.10	1.52	26.55	1.12	1.93
150-160	2.50	34.81	1.63	3.37	1.18	34.81	0.77	1.59
160-170	1.20	57.20	0.51	1.89	0.56	57.20	0.24	0.89
170-180	1.08	56.32	0.47	1.69	0.51	56.32	0.22	0.80
180-190	0.82	64.84	0.29	1.35	0.38	64.84	0.14	0.63
>=190	2.32	56.80	1.00	3.64	1.09	56.80	0.47	1.71

The small DBH class of 10-20 cm has a carbon density of 7.38 tonnes ha^{-1}, which increases gradually with increase in DBH class, till it reaches a peak of 8.54 tonnes ha^{-1} in 50-60 DBH Class, and then starts decreasing gradually with increasing DBH. Similar trends are observed for total estimates for biomass and carbon (Figure 3.1).

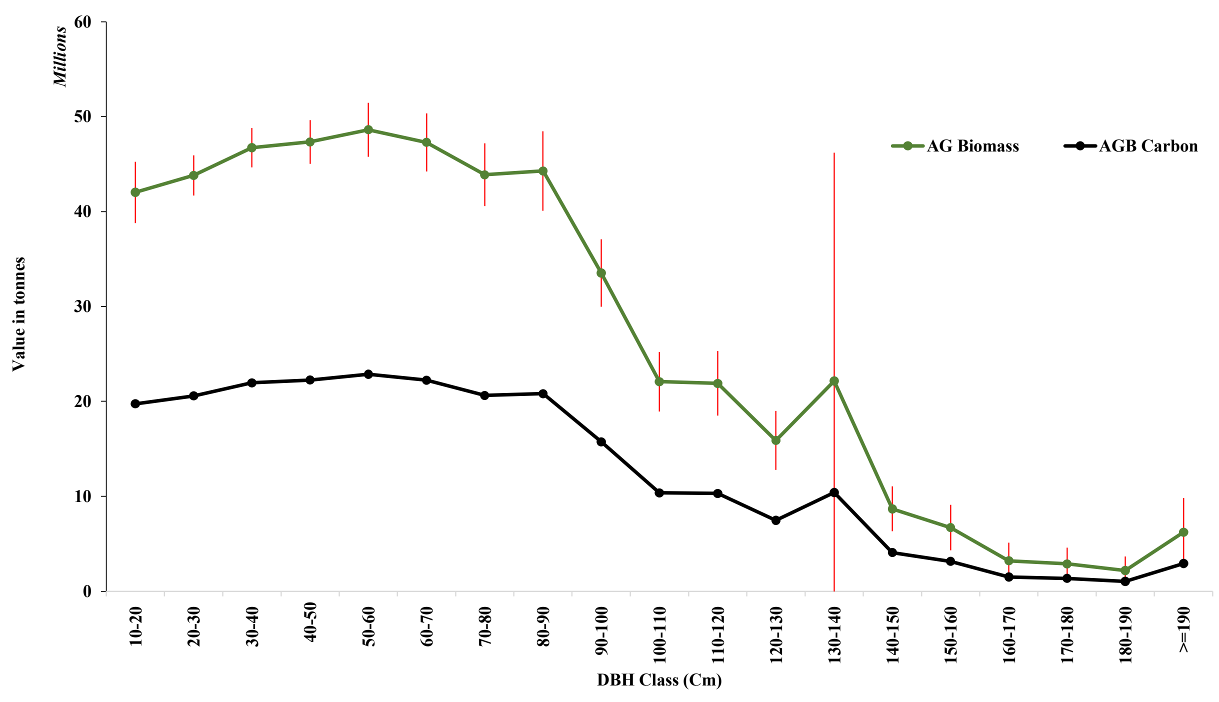

Figure 3.4 Total tree biomass and carbon estimates by DBH Class

Height Class

Table 3.7 and Figure 3.5 show the biomass and carbon density and total estimates of trees by Height Class. Height is grouped into nine (9) different classes. The minimum carbon density is recorded in the smallest Height Class of < 5 metre (0.69 tonnes ha^{-1}), increasing rapidly to 18.54 tonnes ha^{-1} at the 15-20 m class, and then starts to decline thereafter.

Table 3.7 Biomass and Carbon density by Tree Height Class

Height Class (m)	AGB (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
<5	1.47	18.48	1.20	1.74	0.69	18.48	0.56	0.82
5-10	17.44	7.27	16.17	18.71	8.20	7.27	7.60	8.79
10-15	37.14	24.38	28.09	46.20	17.46	24.38	13.20	21.71
15-20	39.46	5.65	37.22	41.69	18.54	5.65	17.50	19.59
20-25	39.32	6.92	36.60	42.05	18.48	6.92	17.20	19.76
25-30	28.28	8.78	25.80	30.76	13.29	8.78	12.12	14.46
30-35	14.72	12.65	12.86	16.58	6.92	12.65	6.04	7.79
35-40	7.05	17.44	5.82	8.28	3.31	17.44	2.74	3.89
>= 40	5.43	27.58	3.93	6.93	2.55	27.58	1.85	3.26

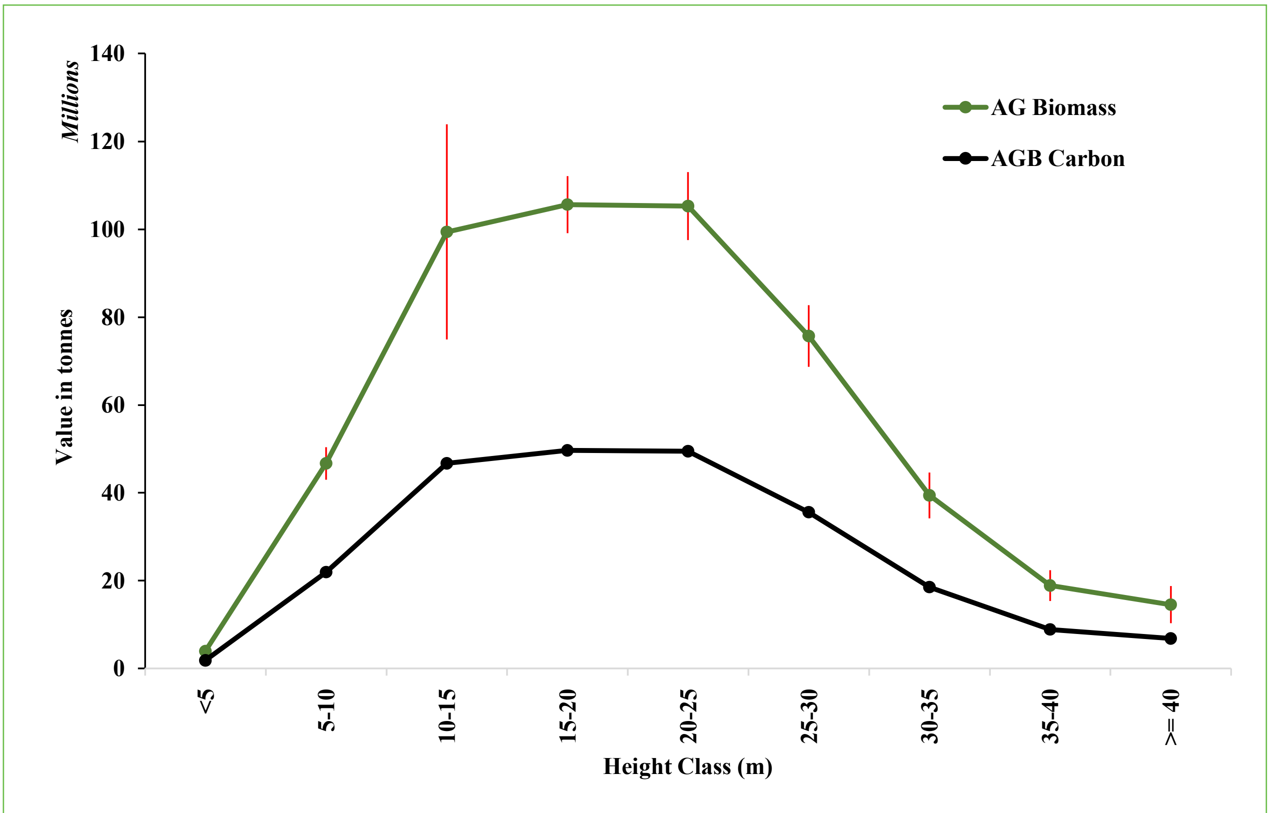

Figure 3.5 Total estimates for Biomass and Carbon by Height Class

3.2.1.2 Sapling

All tree species with a DBH =>5 cm and <10 cm are considered *'saplings'* and constitutes 1.8 % of the total carbon in the AGB carbon pool. Saplings have a total AGB Carbon of 4.33 million tonnes which translates to a carbon density of 1.62 tonnes ha^{-1}(Table 3.8).

Table 3.8 Biomass and Carbon estimate of Sapling (AGB)

Attribute	Density (tonnes ha^{-1})				Total (million tonnes)			
	Estimate	MoE (%)	Lower Limit	Upper Limit	Estimate	MoE (%)	Lower Limit	Upper Limit
Biomass	3.44	41.47	2.01	4.87	9.21	41.51	5.39	13.03
Carbon	1.62	41.47	0.95	2.29	4.33	41.51	2.53	6.12

Species

Rhododendron spp. constitutes the largest carbon stock amongst the sapling with a total of 1.30 million tonnes of Carbon. *Quercus spp.* which saw the greatest carbon content in the *"Tree"* category has a total of 0.21 million tonnes of carbon recorded for the sapling. Table 3.9 shows the detailed list of biomass and carbon estimates for sapling by species.

Table 3.9 Biomass and Carbon estimates by Species

Land Cover	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Abies densa	0.14	37.56	0.09	0.19	0.07	37.56	0.04	0.09
Acer spp.	0.84	77.21	(0.65)	2.32	0.39	77.21	(0.30)	1.09
Ailanthus integrifolia	0.01	95.11	0.00	0.02	0.00	95.11	0.00	0.01
Alnus spp.	0.04	79.59	0.01	0.08	0.02	79.59	0.00	0.04
Aphanamixis polystachya	0.03	46.87	0.01	0.04	0.01	46.87	0.01	0.02
Beilschmiedia spp.	0.04	31.33	0.03	0.05	0.02	31.33	0.01	0.02
Betula spp.	0.12	54.37	0.06	0.19	0.06	54.37	0.03	0.09
Bombax ceiba	0.00	60.56	(0.00)	0.00	0.00	60.56	(0.00)	0.00
Castanopsis spp.	0.22	26.44	0.16	0.28	0.10	26.44	0.08	0.13
Cupressus spp.	0.00	41.84	(0.00)	0.00	0.00	41.84	(0.00)	0.00
Duabanga grandiflora	0.00	24.70	(0.00)	0.00	0.00	24.70	(0.00)	0.00
Engelhardtia spicata	0.05	35.31	0.03	0.07	0.02	35.31	0.02	0.03
Exbucklandia populnea	0.01	56.86	0.00	0.02	0.01	56.86	0.00	0.01
Juglans regia	0.00	77.91	0.00	0.01	0.00	77.91	0.00	0.00
Juniperus spp.	0.05	50.65	0.02	0.07	0.02	50.65	0.01	0.03
Larix griffithii	0.00	25.15	(0.00)	0.01	0.00	25.15	(0.00)	0.00
Magnolia spp.	0.01	46.61	0.01	0.01	0.00	46.61	0.00	0.01
Persea spp.	0.19	20.08	0.15	0.23	0.09	20.08	0.07	0.11
Phoebe goalparensis	0.00	77.71	0.00	0.01	0.00	77.71	0.00	0.00
Picea spinulosa	0.01	47.96	0.01	0.02	0.01	47.96	0.00	0.01

Pinus roxburghii	0.09	50.04	0.05	0.14	0.04	50.04	0.02	0.06
Pinus wallichiana	0.14	47.46	0.07	0.21	0.07	47.46	0.03	0.10
Quercus spp.	0.45	22.23	0.35	0.54	0.21	22.23	0.16	0.26
Rhododendron spp.	2.77	90.16	0.27	5.27	1.30	90.16	0.13	2.48
Schima wallichii	0.07	35.38	0.05	0.10	0.03	35.38	0.02	0.05
Sterculia villosa	0.01	60.37	0.00	0.01	0.00	60.37	0.00	0.00
Symplocos spp.	0.59	16.43	0.50	0.69	0.28	16.43	0.23	0.33
Taxus baccata	0.00	50.49	(0.00)	0.00	0.00	50.49	(0.00)	0.00
Terminalia myriocarpa	0.00	77.16	0.00	0.01	0.00	77.16	0.00	0.00
Tetrameles nudiflora	0.00	164.91	(0.00)	0.00	0.00	64.91	(0.00)	0.00
Tsuga dumosa	0.02	59.77	0.01	0.04	0.01	59.77	0.00	0.02
Others	3.66	7.83	3.37	3.94	1.72	7.83	1.58	1.85

3.2.1.3 Shrub

Shrub is a single or multi-stem woody perennial plant, generally more than 0.5 m and less than 5 m high at maturity without a definite crown. Shrub data are collected through destructive sampling in a 5 m x 5 m plot laid out in the *"carbon plot"*. The plot design and estimation procedures are explained in Chapter 2: Methodology. Shrubs constitute 1.73 million tonnes of Carbon with a density of 0.65 tonnes ha^{-1} (Table 3.10).

Table 3.10 Biomass and Carbon estimate of Shrub (AGB)

Attribute	Density (tonnes ha^{-1})				Total (million tonnes)			
	Estimate	MoE (%)	Lower Limit	Upper Limit	Estimate	MoE (%)	Lower Limit	Upper Limit
Biomass	1.38	21.11	1.09	1.67	3.68	21.19	2.90	4.47
Carbon	0.65	21.11	0.51	0.78	1.73	21.19	1.36	2.10

3.2.1.4 Herb

For NFI, Herbs are any soft-stemmed plant with a height equal to or less than 1 meter. Herb data are also collected through destructive sampling in a 2 m x 2 m plot laid inside the shrub plot. Herbs are the smallest and have the least contribution to the AGB Carbon pool with just 0.53 million tonnes of carbon. This translates to a carbon density of 0.2 tonnes ha^{-1}.

Table 3.11 Biomass and Carbon estimate of Herb (AGB)

Attribute	Density (tonnes ha^{-1})				Total (million tonnes)			
	Estimate	MoE (%)	Lower Limit	Upper Limit	Estimate	MoE (%)	Lower Limit	Upper Limit
Biomass	0.42	24.38	0.32	0.52	1.13	24.45	0.85	1.40
Carbon	0.20	24.38	0.15	0.25	0.53	24.45	0.40	0.66

3.2.2 Below-ground Biomass (BGB)

BGB accounts for 13 % of the total carbon stock of Bhutan's Forest. BGB has been estimated for Trees and Saplings, with tree roots accounting for 94 % of the total BGB carbon stock. Trees have 63.05 million tonnes of Carbon compared to 4.33 million tonnes stored by Sapling roots as reflected in Table 3.12.

Table 3.12 Biomass and Carbon estimates for BGB

Carbon Pool Constituent	Biomass				Carbon			
	Biomass (tonnes ha^{-1})	MoE (%)	Total (million tonnes)	MoE (%)	Carbon (tonnes ha^{-1})	MoE (%)	Total (million tonnes)	MoE (%)
Tree	50.12	4.44	134.14	4.81	23.55	4.44	63.05	4.81
Sapling	3.44	41.47	9.21	41.51	1.62	41.47	4.33	41.51

3.2.2.1 Tree

Table 3.13 shows the total as well as density of BGB Biomass and Carbon for Trees. The total below-ground biomass and biomass carbon for Tree is estimated to be 134.14 million tonnes and 63.05 million tonnes respectively. Further, Trees have a BGB Carbon density of 23.55 tonnes ha^{-1}.

Table 3.13 Biomass and Carbon estimate of tree (BGB)

Attribute	Density (tonnes ha^{-1})				Total (million tonnes)			
	Estimate	MoE (%)	Lower Limit	Upper Limit	Estimate	MoE (%)	Lower Limit	Upper Limit
Biomass	50.12	4.44	47.89	52.34	134.14	4.81	127.68	140.60
Carbon	23.55	4.44	22.51	24.60	63.05	4.81	60.01	66.08

Since BGB is directly dependent on the AGB, estimates for tree species, DBH and Height class show similar trends as in 3.2.1 Above-ground Biomass (AGB) Carbon. The estimates for the same are shown in the following sections:

Species

Table 3.14 and Figure 3.6 show the total estimates and density of the biomass and carbon estimates of tree species (BGB). *Quercus spp.* has the greatest carbon stock accounting for 11.47 % of the total carbon while *Bombax ceiba* and *Phoebe goalparensis* have the lowest estimates for total carbon at 0.06 and 0.07 % respectively.

Table 3.14 Total Biomass and Carbon estimates by Species (BGB)

DBH Class	BGB (million tonnes)				BGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bombax ceiba	0.13	77.53	0.03	0.22	0.06	77.53	0.01	0.10
Phoebe goalparensis	0.14	71.68	0.04	0.24	0.06	71.68	0.02	0.11
Larix griffithii	0.14	61.77	0.05	0.23	0.07	61.77	0.03	0.11
Ailanthus integrifolia	0.15	68.96	0.05	0.25	0.07	68.96	0.02	0.12
Juglans regia	0.20	52.41	0.10	0.31	0.09	52.41	0.05	0.14
Sterculia villosa	0.28	46.65	0.15	0.41	0.13	46.65	0.07	0.19

Aphanamixis polystachya	0.30	42.77	0.17	0.42	0.14	42.77	0.08	0.20
Terminalia myriocarpa	0.33	55.51	0.15	0.52	0.16	55.51	0.07	0.24
Duabanga grandiflora	0.34	40.17	0.21	0.48	0.16	40.17	0.10	0.23
Cupressus spp.	0.35	163.36	(0.22)	0.91	0.16	163.36	(0.10)	0.43
Taxus baccata	0.48	41.21	0.28	0.68	0.22	41.21	0.13	0.32
Tetrameles nudiflora	0.49	58.83	0.20	0.77	0.23	58.83	0.09	0.36
Exbucklandia populnea	0.74	54.02	0.34	1.15	0.35	54.02	0.16	0.54
Engelhardtia spicata	1.37	23.56	1.05	1.69	0.64	23.56	0.49	0.80
Alnus spp.	1.57	24.61	1.19	1.96	0.74	24.61	0.56	0.92
Beilschmiedia spp.	1.61	24.24	1.22	2.00	0.76	24.24	0.57	0.94
Magnolia spp.	1.63	25.64	1.21	2.05	0.77	25.64	0.57	0.96
Juniperus spp.	1.78	31.94	1.21	2.34	0.83	31.94	0.57	1.10
Schima wallichii	1.82	21.81	1.42	2.22	0.86	21.81	0.67	1.04
Picea spinulosa	2.07	34.40	1.36	2.79	0.97	34.40	0.64	1.31
Pinus roxburghii	2.24	30.09	1.57	2.91	1.05	30.09	0.74	1.37
Betula spp.	2.89	15.90	2.43	3.35	1.36	15.90	1.14	1.57
Pinus wallichiana	3.42	26.68	2.51	4.34	1.61	26.68	1.18	2.04
Acer spp.	4.00	12.58	3.49	4.50	1.88	12.58	1.64	2.12
Symplocos spp.	4.36	90.67	0.41	8.30	2.05	90.67	0.19	3.90
Tsuga dumosa	5.22	23.69	3.99	6.46	2.45	23.69	1.87	3.04
Rhododendron spp.	6.68	12.17	5.87	7.50	3.14	12.17	2.76	3.52
Persea spp.	6.76	14.39	5.79	7.74	3.18	14.39	2.72	3.64
Castanopsis spp.	6.79	15.89	5.71	7.87	3.19	15.89	2.68	3.70
Abies densa	18.86	14.54	16.12	21.60	8.86	14.54	7.58	10.15
Quercus spp.	23.09	11.16	20.51	25.66	10.85	11.16	9.64	12.06
Others	44.88	5.83	2.62	42.26	47.50	5.83	0.00	1.23

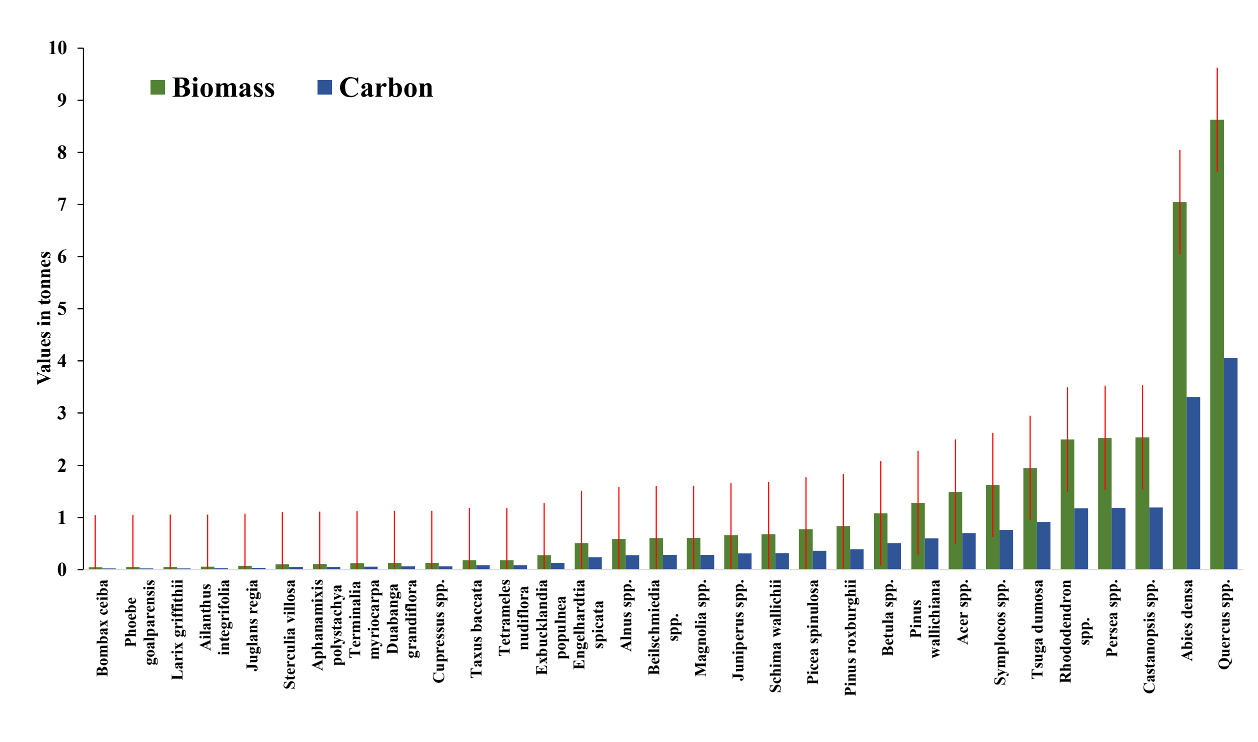

Figure 3.6 Biomass and carbon density for Species (BGB)

DBH Class

The 30-40 DBH class accounts for the greatest carbon content with 10.12 % of the total tree BGB, while the 180-190 DBH class has the smallest carbon content at 0.36 %. The biomass and carbon content in different DBH Class is shown in Table 3.15 and the trend is depicted in Figure 3.7.

Table 3.15 Biomass and carbon density (tonnes ha^{-1}) by DBH Class (BGB)

DBH Class (cm)	BGB (tonnes ha^{-1})				BGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
10-20	5.34	5.85	5.03	5.65	2.51	5.85	2.36	2.66
20-30	5.62	3.77	5.41	5.83	2.64	3.77	2.54	2.74
30-40	5.90	3.55	5.69	6.11	2.77	3.55	2.67	2.87
40-50	5.85	4.09	5.61	6.09	2.75	4.09	2.64	2.86
50-60	5.81	5.12	5.51	6.11	2.73	5.12	2.59	2.87
60-70	5.50	5.88	5.17	5.82	2.58	5.88	2.43	2.74
70-80	4.96	6.98	4.61	5.31	2.33	6.98	2.17	2.49
80-90	4.85	8.54	4.43	5.26	2.28	8.54	2.08	2.47
90-100	3.63	10.10	3.26	3.99	1.71	10.10	1.53	1.88
100-110	2.35	13.64	2.03	2.67	1.10	13.64	0.95	1.25
110-120	2.27	15.00	1.93	2.61	1.07	15.00	0.91	1.23
120-130	1.62	18.87	1.32	1.93	0.76	18.87	0.62	0.91
130-140	1.76	84.13	0.28	3.24	0.83	84.13	0.13	1.52
140-150	0.87	26.42	0.64	1.09	0.41	26.42	0.30	0.51

150-160	0.66	34.69	0.43	0.88	0.31	34.69	0.20	0.41
160-170	0.31	56.76	0.13	0.48	0.14	56.76	0.06	0.23
170-180	0.27	56.09	0.12	0.43	0.13	56.09	0.06	0.20
180-190	0.21	64.73	0.07	0.35	0.10	64.73	0.03	0.16
>=190	0.55	56.13	0.24	0.86	0.26	56.13	0.11	0.41

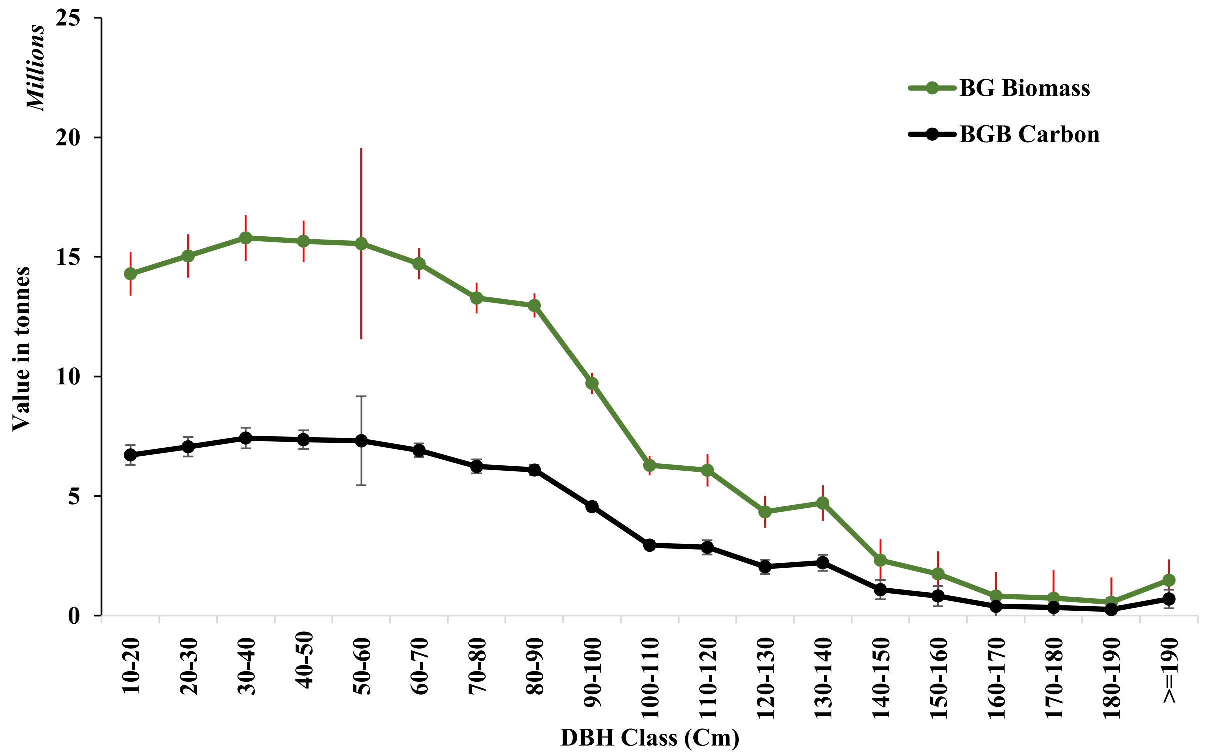

Figure 3.7 Total estimates for biomass and carbon (million tonnes) by DBH Class (BGB)

Height Class

Table 3.16 and Figure 3.1 show the density and total estimates of biomass and carbon for trees by Height Class. Carbon content is greatest at the 15-20 m Height class at 5.58 tonnes ha^{-1} and with a total estimate of 14.9 million tonnes. This accounts for 21 % of the tree carbon estimates.

Table 3.16 Biomass and carbon density by Height Class (BGB)

Height Class (m)	BGB (tonnes ha^{-1})				BGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
<5	0.53	15.46	0.45	0.62	0.25	15.46	0.21	0.29
5-10	5.74	6.14	5.39	6.09	2.70	6.14	2.53	2.86
10-15	10.97	13.89	9.45	12.50	5.16	13.89	4.44	5.87
15-20	11.86	5.01	11.27	12.46	5.58	5.01	5.30	5.86
20-25	11.47	6.31	10.75	12.20	5.39	6.31	5.05	5.73
25-30	8.11	8.19	7.44	8.77	3.81	8.19	3.50	4.12

30-35	4.19	11.84	3.69	4.68	1.97	11.84	1.74	2.20
35-40	2.02	16.70	1.68	2.36	0.95	16.70	0.79	1.11
>= 40	1.49	26.01	1.11	1.88	0.70	26.01	0.52	0.88

Smaller trees <5 m and bigger trees >=40 has the smallest carbon stock at 0.67 million tonnes and 1.88 million tonnes respectively.

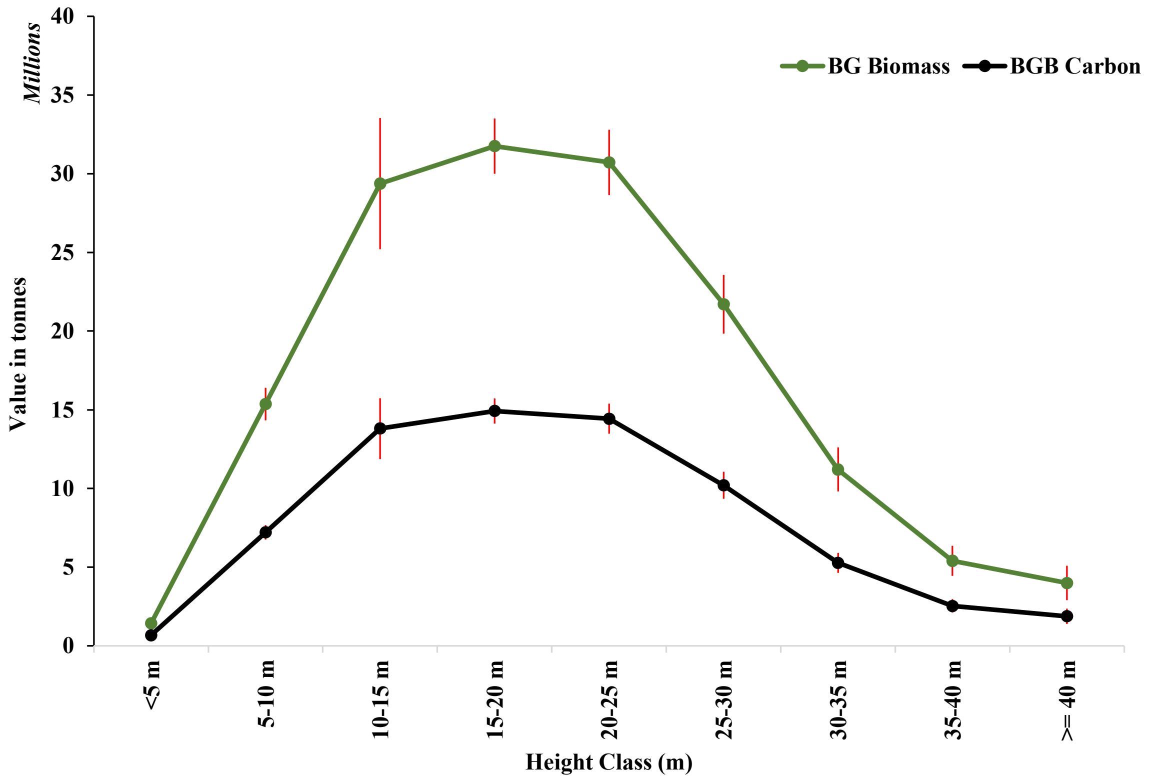

Figure 3.8 Total estimates for biomass and carbon (million tonnes) by Height Class (BGB)

3.2.2.2 Sapling

Saplings account for 6.42 % of the total BGB carbon with total carbon of 4.33 million tonnes, which translates to 1.62 tonnes ha^{-1}.

Table 3.17 Biomass and Carbon estimate for Sapling (BGB)

Attribute	Density (tonnes ha-1)				Total (million tonnes)			
	Estimate	MoE (%)	Lower Limit	Upper Limit	Estimate	MoE (%)	Lower Limit	Upper Limit
Biomass	3.44	41.47	2.01	4.87	9.21	41.51	5.39	13.03
Carbon	1.62	41.47	0.95	2.29	4.33	41.51	2.53	6.12

Species

Table 3.18 shows the total estimate for BGB and carbon estimate of saplings. *Rhododendron spp.* have the greatest carbon estimate accounting for 24 % of the total estimates while *Rhododendron spp, Symplocos spp., Acer spp.* and *Quercus spp.,* account for 42 % of the total BGB carbon estimates.

Table 3.18 Total Estimate for Sapling Biomass and Carbon (BGB)

Species	BGB (million tonnes)				BGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Abies densa	0.06	34.60	0.04	0.08	0.03	34.60	0.02	0.04
Acer spp.	0.21	155.98	(0.12)	0.55	0.10	155.98	(0.06)	0.26
Ailanthus integrifolia	0.00	91.76	0.00	0.01	0.00	91.76	0.00	0.00
Alnus spp.	0.02	72.65	0.00	0.03	0.01	72.65	0.00	0.01
Aphanamixis polystachya	0.01	43.29	0.01	0.02	0.01	43.29	0.00	0.01
Beilschmiedia spp.	0.02	30.07	0.01	0.02	0.01	30.07	0.01	0.01
Betula spp.	0.05	46.70	0.03	0.08	0.02	46.70	0.01	0.04
Bombax ceiba	0.00	160.29	(0.00)	0.00	0.00	160.29	(0.00)	0.00
Castanopsis spp.	0.10	23.91	0.08	0.13	0.05	23.91	0.04	0.06
Cupressus spp.	0.00	141.75	(0.00)	0.00	0.00	141.75	(0.00)	0.00
Duabanga grandiflora	0.00	121.32	(0.00)	0.00	0.00	121.32	(0.00)	0.00
Engelhardtia spicata	0.03	32.81	0.02	0.03	0.01	32.81	0.01	0.02
Exbucklandia populnea	0.01	55.42	0.00	0.01	0.00	55.42	0.00	0.00
Juglans regia	0.00	77.05	0.00	0.00	0.00	77.05	0.00	0.00
Juniperus spp.	0.02	46.52	0.01	0.03	0.01	46.52	0.01	0.02
Larix griffithii	0.00	122.03	(0.00)	0.00	0.00	122.03	(0.00)	0.00
Magnolia spp.	0.00	45.81	0.00	0.01	0.00	45.81	0.00	0.00
Persea spp.	0.09	18.65	0.08	0.11	0.04	18.65	0.04	0.05
Phoebe goalparensis	0.00	74.41	0.00	0.00	0.00	74.41	0.00	0.00
Picea spinulosa	0.01	46.24	0.00	0.01	0.00	46.24	0.00	0.00
Pinus roxburghii	0.04	46.66	0.02	0.06	0.02	46.66	0.01	0.03
Pinus wallichiana	0.06	42.96	0.03	0.09	0.03	42.96	0.02	0.04
Quercus spp.	0.20	20.06	0.16	0.24	0.09	20.06	0.07	0.11
Rhododendron spp.	0.90	60.39	0.35	1.44	0.42	60.39	0.17	0.68
Schima wallichii	0.03	33.50	0.02	0.05	0.02	33.50	0.01	0.02
Sterculia villosa	0.00	58.75	0.00	0.00	0.00	58.75	0.00	0.00
Symplocos spp.	0.27	15.09	0.23	0.31	0.13	15.09	0.11	0.14
Taxus baccata	0.00	145.53	(0.00)	0.00	0.00	145.53	(0.00)	0.00
Terminalia myriocarpa	0.00	76.29	0.00	0.00	0.00	76.29	0.00	0.00
Tetrameles nudiflora	0.00	161.31	(0.00)	0.00	0.00	161.31	(0.00)	0.00
Tsuga dumosa	0.01	55.83	0.01	0.02	0.01	55.83	0.00	0.01
Others	1.57	6.89	1.46	1.68	0.74	6.89	0.69	0.79

3.2.3 Coarse Woody Debris

The DOM accounts for 5.38 % of the total carbon stock of the Forest. The DOM constitutes the CWD and litter which accounts for 1.61 % and 3.76 % respectively of the total carbon stock. The CWD is collected along the 50 m transect to "N" and "E" plots from the "L" plot; the design and estimation procedures are explained in Chapter 2 Methodology. Table 3.19 shows the density and total estimates for Biomass and Carbon for the CWD.

Table 3.19 Biomass and Carbon Estimates for the Coarse Woody Debris

Attribute	Density (tonnes ha^{-1})				Total (million tonnes)			
	Estimate	MoE (%)	Lower Limit	Upper Limit	Estimate	MoE (%)	Lower Limit	Upper Limit
Biomass	6.72	11.73	5.93	7.51	17.99	11.88	15.86	20.13
Carbon	3.16	11.73	2.79	3.53	8.46	11.88	7.45	9.46

3.2.4 Litter

Litter accounts for 19.71 million tonnes out of the total carbon stock of the Forests (Table 3.20), which translates to 7.37 tonnes ha^{-1}(Table 3.20). Litter samples are collected from a 20 cm x 20 cm sampling frame which is laid inside the herb plot.

Table 3.20 Biomass and Carbon Estimates for the Litter

Attribute	Density (tonnes ha-1)				Total (million tonnes)			
	Estimate	MoE (%)	Lower Limit	Upper Limit	Estimate	MoE (%)	Lower Limit	Upper Limit
Biomass	15.67	13.91	13.49	17.85	41.94	14.04	36.05	47.82
Carbon	7.37	13.91	6.34	8.39	19.71	14.03	16.95	22.48

3.2.5 Soil Organic Carbon

3.2.5.1 Total SOC

Soil samples are collected from three layers; at 0-10 cm, 10-20 cm and 20-30 cm depths, using a 10 cm x10 cm sampling frame. These are sent to the laboratory for analysis and carbon estimation. SOC accounts for 34.80 % of the total Forest Carbon with a total estimate of 182.33 million tonnes, which translates to 68.12 tonnes ha^{-1} (Table 3.21).

Table 3.21 Density and total estimates for SOC

Land Cover	SOC Density (tonnes ha^{-1})				Total SOC (million tonnes)			
	Estimate	MoE (%)	Lower Limit	Upper Limit	Estimate	MoE (%)	Lower Limit	Upper Limit
Forest	68.12	7.44	63.05	73.19	182.33	7.67	168.35	196.31

The SOC is greatest in the 1st layer (0-10 cm) and decreases as we go deeper, with the smallest SOC recorded in the 3rd layer (20-30 cm) (Table 3.22).

Table 3.22 Carbon density and total estimates for different soil layer

Soil Layer	Density (tonnes ha^{-1})				Total (million tonnes)			
	SOC	MoE (%)	Lower Limit	Upper Limit	SOC	MoE (%)	Lower Limit	Upper Limit
0-10 cm	28.71	7.32	26.61	30.81	76.84	7.55	71.04	82.64
10-20 cm	22.26	9.59	20.13	24.40	59.59	9.77	53.77	65.41
20-30 cm	17.15	9.70	15.48	18.81	45.90	9.88	41.36	50.43

The AGB, BGB, CWD and Litter constitute the Biomass carbon, which in addition to the SOC account for the total Carbon stock of the Forest.

3.3 Discussion

Bhutan's Forest has a total carbon stock of 523.87 million which translates to about 195.73 tonnes ha^{-1}. Biomass carbon accounts for 65 % of the total carbon stock while SOC accounts for 35 % of the total carbon stock. The carbon density is greater than the global average of 163 tonnes ha^{-1}(FAO, 2020), and the average per ha carbon of 100.92 tonnes ha^{-1} for India at the National level (FSI, 2021). Further, (Aryal et al., (2018) reported 162.95 tonnes ha^{-1} of carbon from Community Forests in Nepal while Mandal et al., (2013) reported a carbon density estimate of 197.10, 222.58, and 274.66 tonnes ha^{-1} in Banke-Maraha, Tuteshwarnath, and Gadhanta-Bardibas collaborative Forests respectively in Nepal.

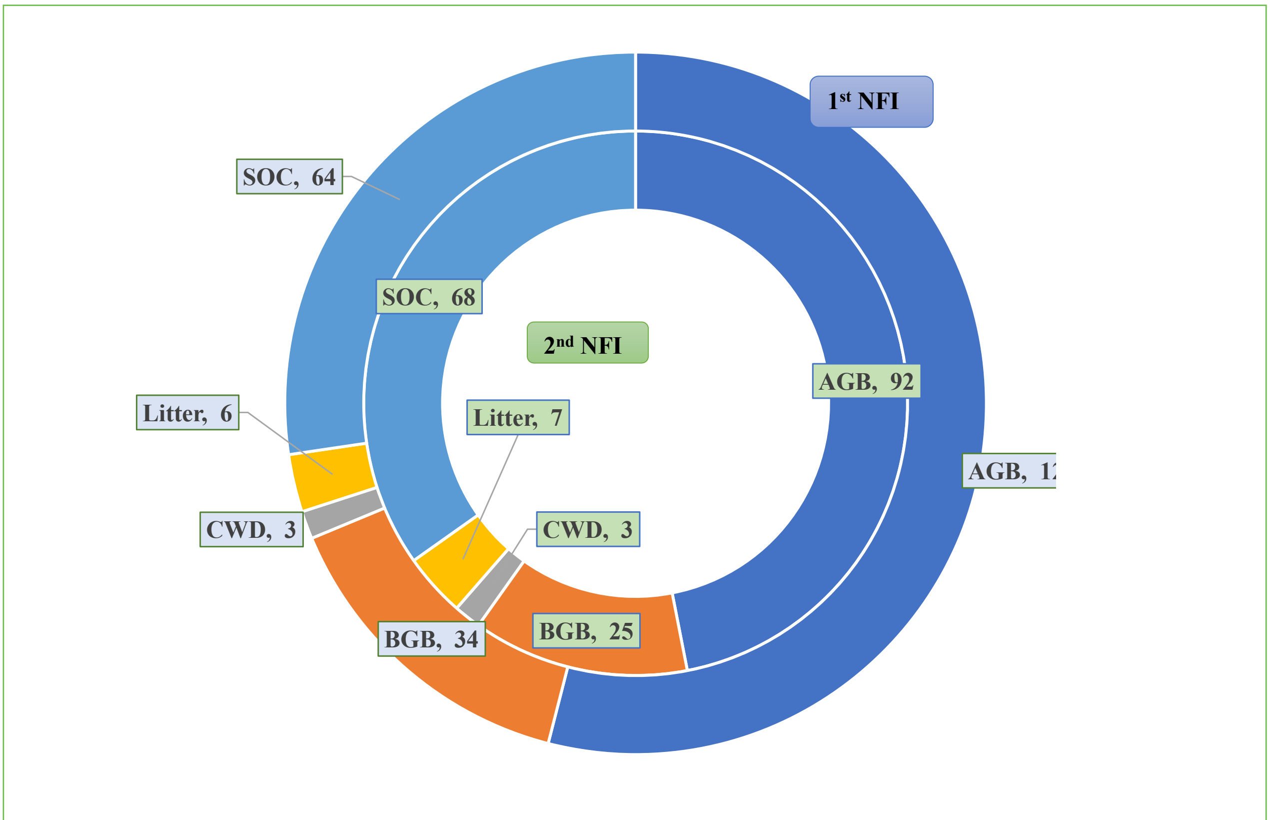

Figure 3.9 Comparison of Carbon stock density (tonnes ha^{-1}) in the 1st and 2nd NFI

At the National level, the carbon density of 195.73 tonnes ha^{-1} is recorded which is smaller than the carbon estimates of 234.27 tonnes ha^{-1} reported for Bhutan in the 1st NFI (DoFPS, 2020; FRMD, 2018b). The comparison between the carbon estimates by different carbon pools is shown in Figure 3.9. The estimates on the outer side are for the 1st NFI, while the estimates on the inner side of the donut are for the 2nd NFI.

There is a decrease of 35 tonnes ha^{-1} and 9 tonnes ha^{-1} respectively for the carbon estimates for the AGB and BGB, while there is a marginal increase of 1 tonne ha^{-1} and 4 tonnes ha^{-1} in Litter and SOC. The change in SOC is negligible. There is an increase in the CWD estimate at 0.13 tonnes ha^{-1}. The decrease in carbon is directly related to the overall decrease in the Forests area, discussed in detail in the National Forest Inventory Volume I: State of Forest Report 2023. One of the main reasons discussed is the removal of bigger trees and replacement of the Forest stand with younger trees. 72 % of the total tree recorded in the NFI has a DBH of less than 30 cm. Further, Forest disturbances in terms of change in land use due to allotment of State Reserve Forest (SRF) for developmental activities, pests and diseases, etc., are other probable reasons for the decrease in biomass carbon. As a result of Forest disturbance, the Forest area has decreased to 2.67 million ha (69.71 %) from 2.73 million ha (71.13 %) in the 1st NFI, corresponding with a similar decrease of growing stock per ha to 283.65 ±10.96 m^3 ha^{-1} which is about 18% decrease from 346 m^3 ha^{-1} for the 1st NFI.

Further, comparison of the pool-wise carbon shows a decrease in carbon density in saplings (AGB) from 12.22 tonnes ha^{-1} in the 1st NFI to 1.62 tonnes ha^{-1} as reported in Table 3.8. As discussed in the *NFI Volume I: State of Forest Report,* the Forest have been generally classified into 11 Forest Types including the Rhododendron Juniper Scrub and Dry Alpine Scrub (DoFPS, 2021a; Grierson & Long, 1983). However, for this NFI, Forests have been classified into 10 major Forest types; Subtropical Forests (STFr), Chir Pine Forests (CPFr), Warm Broadleaved Forests (WBFr), Evergreen Oak Forests (EoFr), Cool Broadleaved Forests (CBFr), Blue Pine Forests (BPFr), Spruce Forests (SPFr), Hemlock Forests (HMFr), Fir Forests (FIFr) and Juniper Rhododendron Forests (JRFr) depending on the "Forest" definition adopted by Bhutan. Therefore, most of the "saplings" recorded in the 1st NFI have been classified into Rhododendron Juniper Scrub. Further, saplings estimate in all plots; L, N and E have been aggregated and their mean was computed at each Cluster Plot (CP) for the 2nd NFI while the sum of the total saplings have been aggregated at the CP level for the earlier estimates.

While there is a decrease in biomass carbon, there is a marginal increase in the SOC. The per ha estimate for SOC for Bhutan's Forest is 68.12 tonnes ha^{-1} which is smaller than the global SOC average of 73.8 tonnes ha^{-1}(FAO, 2020), but is greater than the SOC density of 56.18 tonnes ha^{-1} in India's Forest (FSI, 2021).

As discussed in Chapter 2.2: Estimation Method, the AGB of trees and saplings are estimated using allometric biomass equations and the BGB is accordingly estimated using the root shoot ratio. Only 14 species-specific allometric equations were available during the 1st NFI, while the biomass for rest of the species was estimated by applying the general equations developed for Broadleaved and Coniferous species. Subsequently, the Department worked on developing more allometric equations for better and more accurate estimations of biomass and carbon. Today, 35 species-specific and 2 general allometric equations are available and were used for biomass estimation. Use of species specific equation provides accurate estimate and may be one of the reasons for the change in estimates of tree and sapling biomass.

The biomass and carbon stock are dependent on climate and topographic factors such as elevation, and as a result, differ within the trees and saplings by the DBH and Height Class and in other administrative jurisdictions by Dzongkhag and Forest types. The change in biomass and carbon over the different categories shall be explained in detail in Chapter 4.

FOREST CARBON BY DIFFERENT CATEGORY

4 FOREST CARBON BY DIFFERENT CATEGORY

4.1 Introduction

Bhutan's Forests recorded a total carbon stock of 523.87 million tonnes of carbon with a carbon density of 195.73 tonnes ha^{-1}. These include a total biomass carbon of 341.54 million tonnes of carbon and a SOC of 182.33 million tonnes, which translates to 127.61 tonnes ha^{-1} of bio mass carbon and 68.12 tonnes ha^{-1} of SOC. This carbon stock is distributed by different Dzongkhags, Forest Types and across elevation gradients. These areas have different climatic factors (temperature, precipitation, water, etc.), edaphic factors (soil types, soil properties, etc.) and topographic factors (elevation, slopes, terrain, etc.). These factors directly or indirectly influence the distribution of the vegetation, vegetation types, growth and development of Forest stands which results in differences in the distribution of biomass and carbon stock across the country.

Biomass and Carbon stock are reported by Dzongkhag, Forest Type, and Elevation range. This chapter further discusses the distribution and change in biomass and carbon stock over the 2 NFIs.

4.2 Dzongkhag

Table 4.1 shows the total carbon stock by Dzongkhag. Total carbon stock ranges from 7.17 million tonnes in Tsirang to 53.86 million tonnes in Wangdue Phodrang. Wangdue Phodrang, Zhemgang, Lhuentse, Trongsa, Bumthang, Mongar and Trashigang contribute more than 50% of the total carbon stock at the national level while other 13 Dzongkhags contribute less than 50% of the total carbon stock. Carbon density in the Dzongkhags varies significantly; from 121.31 tonnes ha^{-1} in Samdrup Jongkhar to about 255.1 tonnes ha^{-1} in Haa Dzongkhag as described in Table 4.2.

Table 4.1 Total Carbon estimate at Dzongkhag Level (million tonnes)

Dzongkhag	AGB	BGB	CWD	Litter	SOC	Total
Bumthang	14.40	3.80	1.05	2.11	12.85	34.20
Chhukha	12.24	3.33	0.23	2.36	9.08	27.24
Dagana	13.50	3.60	0.65	1.03	10.94	29.71
Gasa	5.55	1.42	0.14	0.60	4.98	12.69
Haa	13.17	3.45	0.48	0.97	13.44	31.52
Lhuentse	19.89	5.12	0.45	0.71	12.57	38.75
Mongar	17.06	4.48	0.34	0.77	11.49	34.14
Paro	6.92	1.80	0.27	0.79	6.29	16.06
Pemagatshel	5.27	1.46	0.08	0.62	3.42	10.85
Punakha	8.56	2.29	0.26	0.39	7.58	19.07
Samdrup Jongkhar	11.03	3.02	0.32	0.77	5.74	20.88
Samtse	6.26	1.73	0.12	0.47	5.88	14.48
Sarpang	11.62	3.12	0.49	0.87	8.93	25.02

Thimphu	7.79	2.03	0.14	0.46	5.70	16.12
Trashigang	16.11	4.21	0.53	1.09	11.59	33.54
Trashi Yangtse	9.02	2.35	0.29	0.76	7.60	20.02
Trongsa	16.39	4.24	0.67	1.92	11.25	34.48
Tsirang	3.67	1.01	0.09	0.26	2.14	7.17
Wangdue Phodrang	25.19	6.67	1.17	1.21	19.62	53.86
Zhemgang	25.27	6.19	0.74	1.37	10.83	44.40

Table 4.2 Carbon deestimate by Dzongkhag level (tonnes ha^{-1})

Dzongkhag	AGB	BGB	CWD	Litter	SOC	Total
Bumthang	101.41	26.74	7.37	14.84	90.45	240.81
Chhukha	75.12	20.45	1.41	14.52	55.76	167.26
Dagana	88.02	23.44	4.22	6.70	71.34	193.72
Gasa	84.72	21.76	2.19	9.14	76.05	193.86
Haa	106.59	27.95	3.90	7.85	108.81	255.11
Lhuentse	110.82	28.54	2.49	3.98	70.04	215.87
Mongar	99.55	26.16	1.96	4.48	67.08	199.24
Paro	92.59	24.04	3.59	10.60	84.14	214.96
Pemagatshel	59.36	16.48	0.90	6.99	38.58	122.30
Punakha	96.45	25.81	2.89	4.45	85.45	215.05
Samdrup Jongkhar	64.07	17.54	1.87	4.48	33.35	121.30
Samtse	62.77	17.37	1.25	4.73	58.97	145.09
Sarpang	80.19	21.50	3.38	5.97	61.62	172.65
Thimphu	95.48	24.92	1.67	5.67	69.84	197.57
Trashigang	98.93	25.85	3.25	6.68	71.18	205.89
Trashi Yangtse	110.19	28.77	3.52	9.26	92.91	244.65
Trongsa	111.69	28.92	4.60	13.06	76.65	234.91
Tsirang	67.57	18.58	1.61	4.73	39.35	131.84
Wangdue Phodrang	97.26	25.75	4.50	4.67	75.78	207.96
Zhemgang	113.26	27.76	3.31	6.16	48.56	199.05

Table 4.3 shows the soil carbon density and total soil carbon stock in 20 Dzongkhags. The SOC density is smallest in Samdrup Jongkhar with 33.35 tonnes ha^{-1} and greatest in Haa with a SOC density of 108.81 tonnes ha^{-1}. However, the total SOC stock is greatest in Wangdue Phodrang (19.62 million tonnes) and smallest in Tsirang Dzongkhag (2.14 million tonnes). The SOC density decreases with the soil depth and Figure 4.1 shows the variation of total SOC stock in different soil layers by Dzongkhag.

Table 4.3 Total and carbon density estimates of SOC by Dzongkhag

Dzongkhag	SOC (tonnes ha^{-1})				SOC (million tonnes)			
	Carbon	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	90.45	25.61	67.28	113.61	12.85	26.75	3.44	9.41
Chhukha	55.76	23.58	42.61	68.91	9.08	24.19	2.20	6.89
Dagana	71.34	28.83	50.77	91.91	10.94	29.39	3.22	7.73
Gasa	76.05	39.33	46.14	105.96	4.98	39.74	1.98	3.00
Haa	108.81	46.46	58.26	159.37	13.44	47.27	6.35	7.09
Lhuentse	70.04	19.13	56.63	83.44	12.57	20.44	2.57	10.00
Mongar	67.08	22.93	51.70	82.46	11.49	23.56	2.71	8.79
Paro	84.14	33.64	55.83	112.44	6.29	35.38	2.22	4.06
Pemagatshel	38.58	44.42	21.44	55.71	3.42	45.12	1.54	1.88
Punakha	85.45	22.42	66.29	104.61	7.58	24.38	1.85	5.73
Samdrup Jongkhar	33.35	26.46	24.52	42.17	5.74	26.96	1.55	4.19
Samtse	58.97	27.54	42.73	75.21	5.88	29.02	1.71	4.18
Sarpang	61.62	27.31	44.79	78.44	8.93	28.04	2.50	6.43
Thimphu	69.84	31.16	48.07	91.60	5.70	32.53	1.85	3.84
Trashigang	71.18	27.03	51.95	90.42	11.59	28.02	3.25	8.35
Trashi Yang-tse	92.91	16.89	77.22	108.60	7.60	19.85	1.51	6.09
Trongsa	76.65	44.28	42.71	110.58	11.25	44.86	5.05	6.20
Tsirang	39.35	46.39	21.10	57.60	2.14	47.90	1.02	1.11
Wangdue Phodrang	75.78	20.32	60.38	91.18	19.62	21.20	4.16	15.46
Zhemgang	48.56	37.68	30.26	66.86	10.83	37.89	4.10	6.73

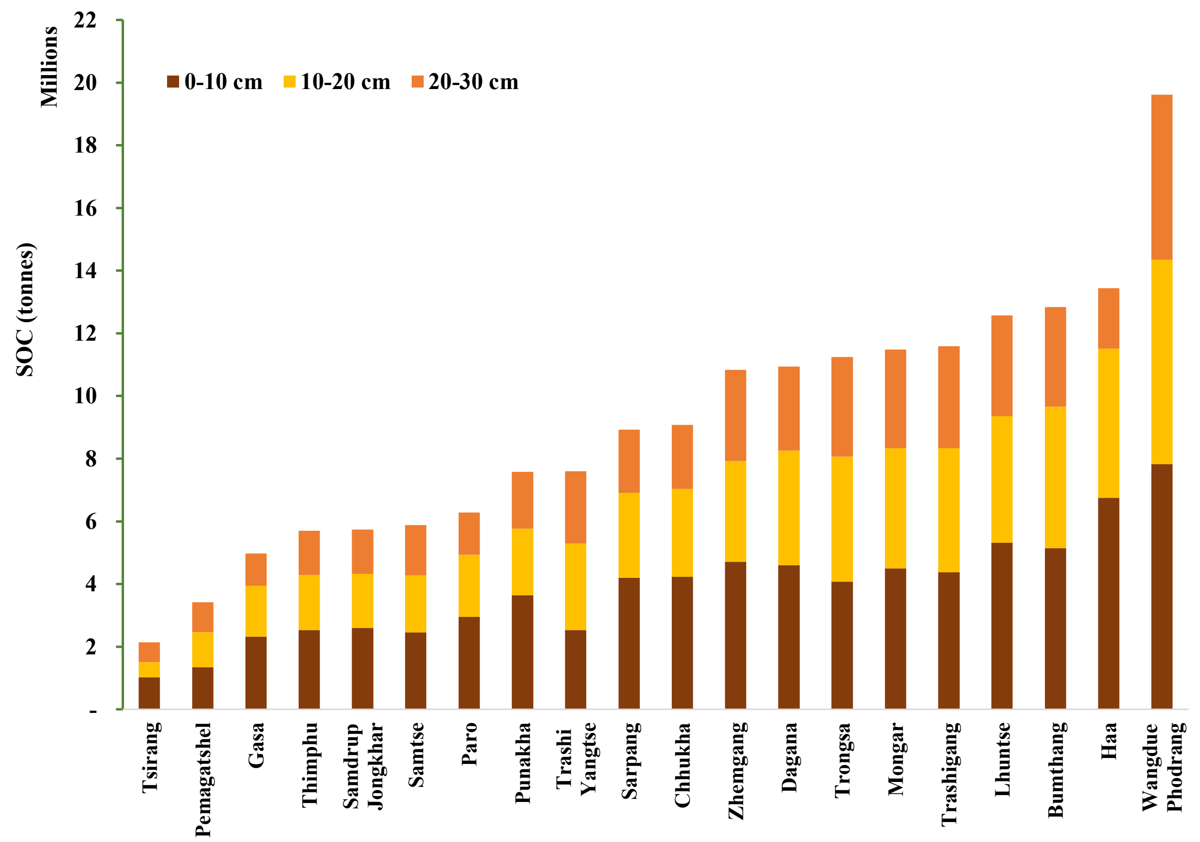

Figure 4.1 SOC in different soil layer by Dzongkhag

4.3 Forest Type

Total carbon density is greater in Coniferous Forests compared to the Broadleaved Forests while the total carbon stock is greater in Broadleaved Forests. Broadleaved Forests have greater carbon densities in the AGB and BGB carbon pools while Coniferous Forests have greater carbon densities in CWD, litter and SOC pools (Table 4.4).

Table 4.4 Carbon density and total estimates by different Forest Class

Carbon Pool	Per ha estimates (tonnes ha^{-1})		Total in million tonnes	
	Broadleaved Forest	Coniferous Forest	Broadleaved Forest	Coniferous Forest
AGB	92.48	90.56	168.28	77.60
BGB	24.26	23.89	44.15	20.48
CWD	2.72	4.22	4.95	3.61
Litter	6.56	9.46	11.94	8.11
SOC	62.65	81.95	114.00	70.22
Total	188.68	210.08	343.32	180.01

Table 4.5 and Table 4.6 shows the total carbon stock and total carbon density by Forest Types in different carbon pools. The total carbon stock is greatest in Cool Broadleaved Forests with 189.15 million tonnes and smallest in Chir Pine Forests with 7.49 million tonnes. The total carbon density varies significantly among the Forest Types, and it ranges from 95.47 tonnes ha^{-1} in Chir Pine Forests to 263.21 tonnes ha^{-1} in Hemlock Forests.

Table 4.5 Total Carbon estimate for Different Carbon Pools by Forest Type (million tonnes)

Forest Type	AGB	BGB	CWD	Litter	SOC	Total
BPFr	6.02	1.65	0.32	1.42	4.90	14.31
CBFr	92.85	24.05	3.01	5.99	63.25	189.15
CPFr	3.62	1.03	0.13	0.61	2.10	7.49
EOFr	4.80	1.24	0.06	0.23	3.36	9.69
FIFr	49.68	12.96	2.31	4.42	41.27	110.64
HMFr	15.98	4.14	1.05	1.06	12.09	34.32
JRFr	2.53	0.71	0.06	0.27	6.46	10.03
SPFr	4.88	1.25	0.13	0.09	3.83	10.17
STFr	18.26	5.16	0.39	1.95	12.34	38.09
WBFr	56.11	14.62	1.66	3.83	36.86	113.07

Table 4.6 Carbon density of different carbon pool by Forest Type (tonnes ha^{-1})

Forest Type	AGB	BGB	CWD	Litter	SOC	Total
BPFr	58.18	15.97	3.12	13.74	47.31	138.32
CBFr	123.10	31.89	3.99	7.94	83.86	250.79
CPFr	46.13	13.16	1.64	7.76	26.78	95.47
EOFr	118.14	30.54	1.37	5.68	82.62	238.35
FIFr	114.82	29.95	5.34	10.22	95.40	255.72
HMFr	122.55	31.75	8.05	8.17	92.70	263.21
JRFr	36.23	10.23	0.81	3.90	92.75	143.92
SPFr	115.51	29.62	2.97	2.16	90.60	240.86
STFr	51.28	14.49	1.08	5.46	34.66	106.97
WBFr	83.91	21.86	2.48	5.73	55.13	169.10

Table 4.7 shows the SOC density and total SOC stock by different Forest Types. The SOC density is greatest in Fir Forests (95.40 tonnes ha^{-1}) and smallest in Subtropical Forests (34.66 tonnes ha^{-1}). However, the total SOC stock is greatest in cool Broadleaved Forests and smallest in Chir Pine Forests. Figure 4.2 shows the total soil carbon stock in Forest Type by soil depth.

Table 4.7 SOC density and total estimates by Forest Type

Forest Type	SOC (tonnes ha^{-1})				SOC (million tonnes)			
	Carbon	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	47.31	31.95	32.20	62.42	4.90	31.96	3.33	6.46
CBFr	83.86	9.87	75.58	92.14	63.25	10.10	56.86	69.64
CPFr	26.78	65.98	9.11	44.44	2.10	65.99	0.71	3.48
EOFr	82.62	67.76	26.64	138.60	3.36	67.76	1.08	5.63
FIFr	95.40	16.45	79.70	111.09	41.27	16.54	34.45	48.10
HMFr	92.70	25.80	68.78	116.61	12.09	25.82	8.97	15.21
JRFr	92.75	18.56	75.54	109.96	6.46	18.57	5.26	7.66
SPFr	90.60	18.55	73.80	107.41	3.83	18.55	3.12	4.54
STFr	34.66	20.95	27.39	41.92	12.34	21.01	9.75	14.93
WBFr	55.13	14.30	47.24	63.01	36.86	14.45	31.54	42.19

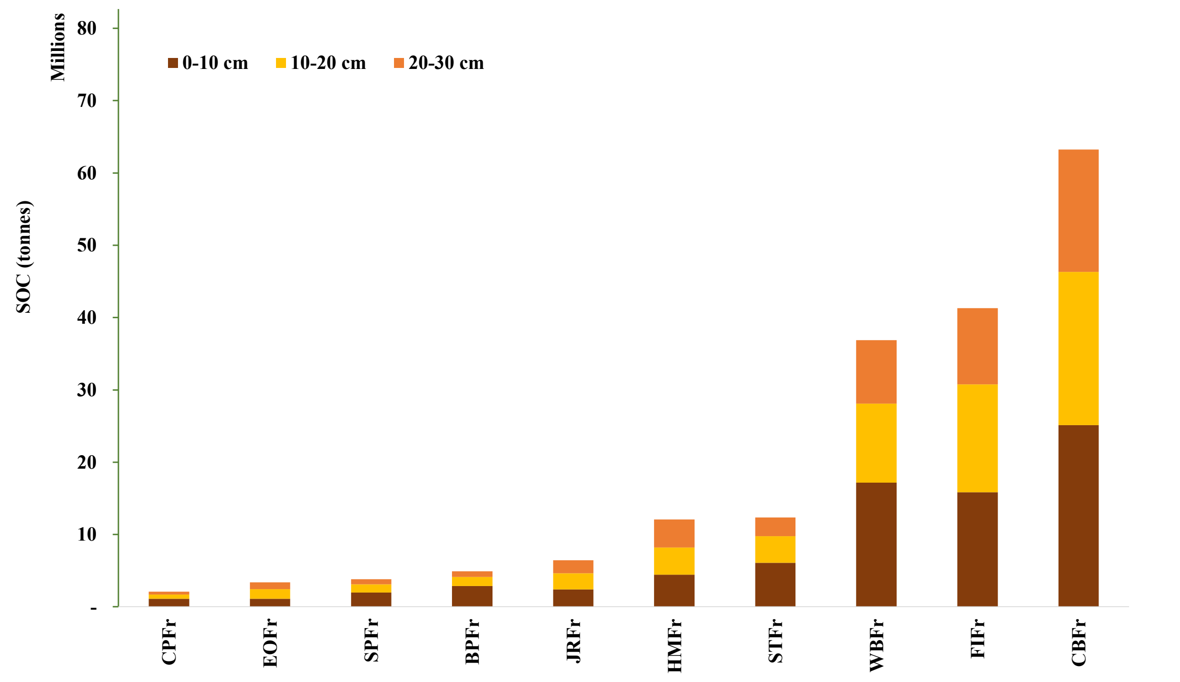

Figure 4.2 Total SOC in different soil layer by Forest Type

4.4 Estimates by Elevation

Table 4.8 and Table 4.9 shows the total carbon stock and total carbon density in the Forest by elevation. Total carbon stock and carbon density increases with elevation and peaks at the mid-elevation of 2000-3000 m.a.s.l and then declines.

Table 4.8 Total Carbon stock by Elevation (million tonnes)

Elevation	AGB	BGB	CWD	Litter	SOC	Total
<1000	17.73	5.01	0.38	1.83	11.61	36.55
1000-2000	59.89	15.76	1.91	5.05	42.21	124.82
2000-3000	103.09	26.66	3.24	6.52	67.05	206.57
3000-4000	65.55	17.18	3.03	5.71	57.48	148.96
>=4000	2.01	0.55	0.02	0.59	6.95	10.12

The carbon density ranges from 101.90 tonnes ha^{-1} in elevation below 1000 m.a.s.l to 241.44 tonnes ha^{-1} in elevation ranging at 2000-3000 m.a.s.l.

Table 4.9 Carbon density by Elevation (t C ha^{-1}yr^{-1})

Elevation	AGB	BGB	CWD	Litter	SOC	Total
<1000	49.43	13.97	1.05	5.10	32.35	101.90
1000-2000	77.91	20.50	2.48	6.58	54.91	162.37
2000-3000	120.49	31.17	3.79	7.62	78.36	241.44
3000-4000	105.00	27.52	4.86	9.14	92.07	238.60
>=4000	29.10	8.00	0.29	8.55	100.44	146.37

Table 4.10 shows the SOC density and stock by elevation. Both the density and stock increases with elevation and peaks at mid elevation of 3000-4000 *m.a.s.l.* The SOC density is smallest in elevation below 1000 *m.a.s.l.* Figure 4.3 shows the total SOC by soil layer and elevation. SOC stock decreases with soil depth as evident from the Figure 4.3.

Table 4.10 SOC stock by Elevation

Elevation (m.a.s.l)	SOC (tonnes ha^{-1})				SOC (million tonnes)			
	Carbon	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
<1000	32.35	22.84	24.96	39.74	11.61	23.25	8.91	14.31
1000-2000	54.91	13.33	47.58	62.23	42.21	13.92	36.33	48.08
2000-3000	78.36	10.65	70.02	86.71	67.05	11.36	59.43	74.66
3000-4000	92.07	11.75	81.25	102.90	57.48	12.47	50.32	64.65

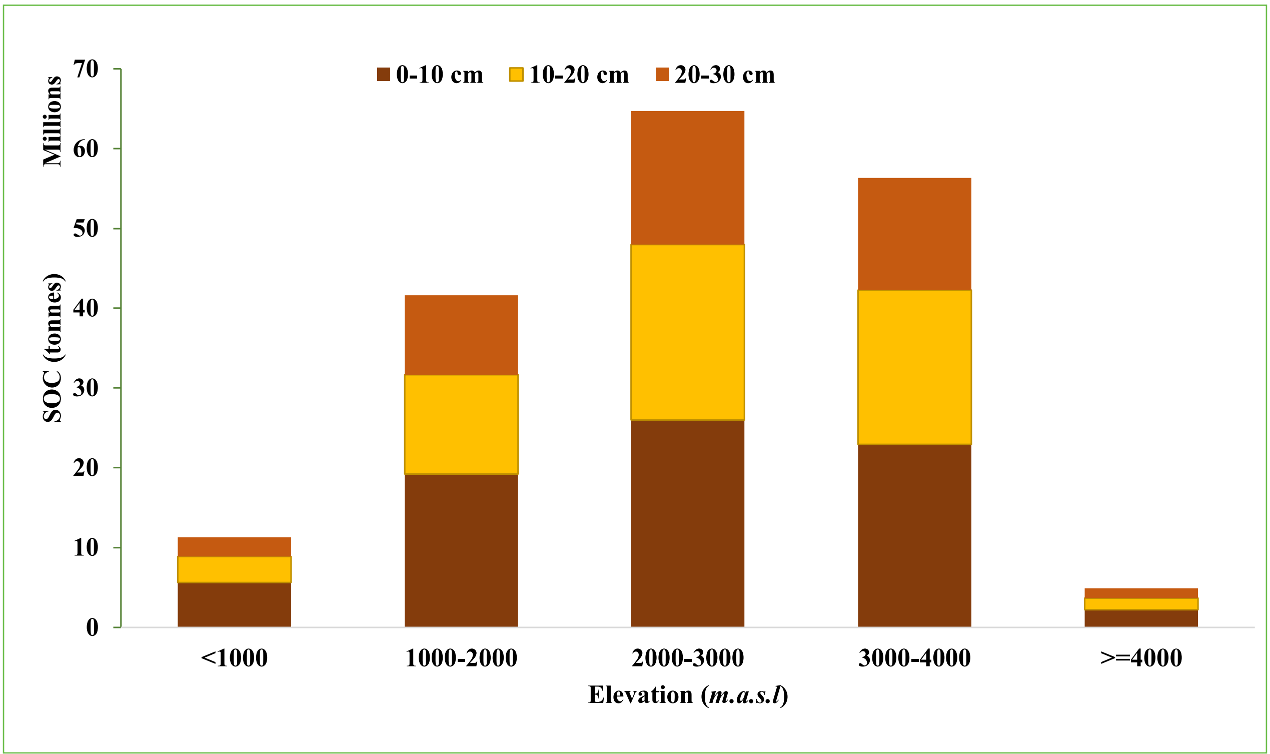

Figure 4.3 SOC stock by soil layer and Elevation

4.5 Discussion

The Carbon density for Bhutan's Forests is 195.73 tonnes ha^{-1} with a biomass carbon density of 127.61 tonnes ha^{-1} and a SOC density of 68.12 tonnes ha^{-1}. Over the two (2) NFIs, the biomass carbon density has decreased in all Forest Types and across all the Elevation Classes. However, the biomass carbon density saw an overall decrease in all Dzongkhags although it has increased in Dagana, Gasa, Paro, Sarpang and Trashi Yangtse Dzongkhags. The major change in biomass density is described in Chapter 3: Forest Biomass and Carbon.

The significant difference in the biomass carbon density among the Dzongkhags can be attributed to differences in the Forest Types (species composition) (Dyola et al., 2022; Nam et al., 2018; Singh & Verma, 2018) and Forest management practices. In general, the Dzongkhags dominated by Fir, Cool Broadleaved, Evergreen Oak, Spruce and Hemlock Forests have greater biomass carbon density than the Dzongkhags dominated by other Forest Types. For example, Samtse, Samdrup Jongkhar, Pemagatshel, Tsirang and Sarpang Dzongkhags, with the majority of their Forests falling under the Subtropical and Warm Broadleaved Forest (DoFPS, 2022), have the smallest biomass carbon density compared to other Dzongkhags.

Further, lower biomass carbon density is also related to the stem and basal area density (Padmakumar et al., 2018; Singh & Verma, 2018). Except for Pemagatshel Dzongkhag, most of the Dzongkhags with lower stem density and lower basal area per unit area, have the smallest biomass carbon density. For example, Bumthang (41.57 m^2 ha^{-1}), Haa (39.54 m^2 ha^{-1}), Lhuentse (37.27 m^2 ha^{-1}), Trashi Yangtse (39.39 m^2 ha^{-1}) and Trongsa (38.86 m^2 ha^{-1}) Dzongkhags with greater basal areas *(FMID 2023)* also have greater biomass carbon density compared to rest.

There is a significant difference in SOC density among the Dzongkhags. SOC density in eight Dzongkhags of Chhukha, Lhuentse, Pemagatshel, Samdrup Jongkhar, Thimphu, Trashi Yangtse, Trongsa and Zhemgang has decreased from the 1st NFI while there a marginal increase is observed in other Dzongkhags. The change in SOC density in Dzongkhags cannot be explained with available data and need further investigation. The SOC density is estimated to be greatest in Haa with 108.81 tonnes ha^{-1} and smallest in Samdrup Jongkhar with 33.35 tonnes ha^{-1}. The variation in SOC density is very significant as there is remarkable differences even between the adjoining Dzongkhags. For example, there is a considerable difference in SOC density in neighboring Dzongkhags of Haa (108.81 tonnes ha^{-1}), Samtse (58.97 tonnes ha-^{1}), Chhukha (55.76 tonnes ha^{-1}), Paro (84.14 tonnes ha^{-1}) and Thimphu (69.84 tonnes ha^{-1}). In general, the SOC density is lower in warmer Dzongkhag compared to cooler Dzongkhags. While there no clear explanation for these difference, we assume that the differences in the SOC density among the Dzongkhags may have been influenced by different soil properties, climatic factors, tree species, management (Guan et al., 2019; Lal, 2005), Forest Types and Forest stand (Guan et al., 2019).

Biomass carbon density also varies significantly among the Forest Types. The Juniper Rhododendron Forests have the smallest biomass carbon density of 36.23 tonnes ha^{-1} compared to the greatest biomass carbon density of 123.13 tonnes ha^{-1} in Cool Broadleaved Forests. These differences may be attributed to the species composition (Dyola et al., 2022; Nam et al., 2018; Singh & Verma, 2018), management history (Nam et al., 2018; Ren et al., 2013; Singh & Verma, 2018) and elevation (N. Liu & Nan, 2018; Singh & Verma, 2018; Sun et al., 2020), stand age (Chen et al., 2023; Sun et al., 2020; Xu et al., 2021) and wood density (N. Liu & Nan, 2018; Nam et al., 2018; Petráš et al., 2019). In general, the carbon density is found to be greater in the Coniferous Forests than in Broadleaved Forests. Similar observations were recorded in Western Himalayas of India (Dar et al., 2017; Singh & Verma, 2018).

The biomass carbon density has decreased in all Forest Types from the 1st NFI. The decrease in the biomass carbon density may be due to the use of species-specific allometric equations and differences in the computation of sapling biomass estimates as described in Chapter 3. Further, increase in accessibility of the plots may have also contributed to a decrease in biomass carbon density as a greater number of plots with lower biomass per unit area in all Forest types were included in the analysis and computation of the means.

The SOC density ranges from 26.78 ±17.67 tonnes ha^{-1} in the Chir Pine Forest to 95.40 ±15.69 tonnes ha^{-1} in the Fir Forest. The variation in the SOC density by Forest Types are mainly attributed to edaphic factors (soil types, soil properties (Y. Liu et al., 2016), climatic factors (precipitations, temperature) (Y. Liu et al., 2016; Sheikh et al., 2009) and topographic factors like elevation (Sheikh et al., 2009; Tashi et al., 2016) and leaf litter accumulation, species composition and basal area(Tashi et al., 2016). The variation in the SOC density is also consistent with similar studies in Bhutan (Tashi et al., 2016), Temperate Forests in India and different Forest Types in east China (Y. Liu et al., 2016).

BIOMASS GROWTH AND CARBON SEQUESTRATION

5 BIOMASS GROWTH AND CARBON SEQUESTRATION

5.1 Introduction

The biomass and carbon increment are estimated for tree above-ground carbon pool only, and no estimates are made for other carbon pools. However, the increment for below-ground tree carbon pool may be directly computed using the root-to-shoot ratio as described in Chapter 2: Methodology. The biomass and carbon increment are estimated using the tree ring data collected as part of NFI and it does not account for biomass and carbon lost as part of wood removals harvested. The periodic increment in biomass is estimated using the equation (5.1).

$$B_g = \frac{B_2 - B_1}{5} \qquad (5.1)$$

Where,

Bg,= 5-year periodic annual biomass increment, t d.m ha^{-1} yr^{-1};

B_1 = the biomass of the tree at the beginning of the growth period, t d.m ha^{-1}; and

B_2 = the biomass of the tree at the end of the growth period, t d.m ha^{-1}

B_1 and B_2 are estimated using the allometric biomass equations described in Chapter 2 Methodology.

5.2 Biomass Increment by Different Category

5.2.1 Biomass and Carbon Increment by Land Class

Table 5.1 shows the total periodic annual biomass and carbon increment while Table 5.2 shows periodic annual biomass and carbon increment per ha in the above-ground carbon pool of tree biomass. The biomass increment is greater in Forests compared to Non-Forests with an annual biomass and carbon increment of 6.49 and 3.05 million tonnes respectively in Forests.

Table 5.1 Total above-ground biomass and carbon increment by Land Cover (million tonnes yr^{-1})

Land Cover	AGB Increment				AGB Carbon Increment			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	6.49	9.97	5.84	7.14	3.05	0.00	2.75	3.35
Non-Forest	1.12	64.35	0.40	1.84	0.53	0.00	0.19	0.86

Table 5.2 Above-ground biomass and carbon increment per ha by Land Cover (tonnes ha^{-1} yr^{-1})

Land Cover	AGB Increment				AGB Carbon Increment			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	2.43	9.80	2.19	2.66	1.14	9.80	1.03	1.25
Non-Forest	0.96	64.32	0.34	1.58	0.45	64.32	0.16	0.74

5.2.2 Biomass and Carbon Increment by Dzongkhag

The biomass and carbon increment varies significantly among Dzongkhags. Biomass increment ranges from 0.98 tonnes $ha^{-1}yr^{-1}$ to 5.29 tonnes $ha^{-1}yr^{-1}$ while the carbon increment ranges from 0.46 tonnes $ha^{-1}yr^{-1}$ to 2.49 tonnes $ha^{-1}yr^{-1}$. Pemagatshel saw the greatest biomass and carbon increment in the last five years while Gasa Dzongkhag recorded the smallest biomass and carbon increment. As described in Table 5.3, the biomass and carbon increment in Dagana, Paro, Pemagatshel, Punakha, Samdrup Jongkhar, Thimphu, Trashigang, Tsirang and Zhemgang Dzongkhags are greater than the average annual biomass and carbon increment at the National level.

Table 5.3 Above-ground biomass and carbon increment by Dzongkhag (tonnes $ha^{-1}yr^{-1}$)

Dzongkhag	AGB Increment				AGB Carbon Increment			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	2.12	35.70	1.36	2.88	1.00	35.70	0.64	1.35
Chhukha	2.10	51.10	1.03	3.17	0.99	51.10	0.48	1.49
Dagana	2.72	22.02	2.12	3.32	1.28	22.02	1.00	1.56
Gasa	0.98	34.62	0.64	1.32	0.46	34.62	0.30	0.62
Haa	1.60	35.69	1.03	2.17	0.75	35.69	0.48	1.02
Lhuentse	0.99	69.13	0.31	1.67	0.46	69.13	0.14	0.79
Mongar	2.20	57.36	0.94	3.47	1.04	57.36	0.44	1.63
Paro	3.26	43.96	1.82	4.69	1.53	43.96	0.86	2.20
Pemagatshel	5.29	70.12	1.58	9.00	2.49	70.12	0.74	4.23
Punakha	3.33	37.19	2.09	4.58	1.57	37.19	0.98	2.15
Samdrup Jongkhar	2.54	30.55	1.77	3.32	1.20	30.55	0.83	1.56
Samtse	1.73	25.59	1.29	2.18	0.82	25.59	0.61	1.02
Sarpang	2.24	22.79	1.73	2.75	1.05	22.79	0.81	1.29
Thimphu	2.57	29.94	1.80	3.34	1.21	29.94	0.85	1.57
Trashigang	2.69	25.87	1.99	3.38	1.26	25.87	0.94	1.59
Trashi Yangtse	2.08	44.64	1.15	3.01	0.98	44.64	0.54	1.42
Trongsa	1.58	38.81	0.97	2.20	0.74	38.81	0.45	1.03
Tsirang	3.45	44.56	1.91	4.99	1.62	44.56	0.90	2.34
Wangdue Phodrang	1.82	23.14	1.40	2.24	0.86	23.14	0.66	1.05
Zhemgang	3.87	32.91	2.60	5.14	1.82	32.91	1.22	2.42

Figure 5.1 shows the comparison of total biomass and carbon increment and their contribution to total annual biomass and carbon increment in Forests. Seven Dzongkhags of Zhemgang (0.86 million tonnes yr^{-1}), Wangdue Phodrang (0.47 million tonnes yr^{-1}), Pemagatshel (0.47 million tonnes yr^{-1}), Samdrup Jongkhar (0.44 million tonnes yr^{-1}), Trashigang (0.44 million tonnes yr^{-1}), Dagana (0.42 million tonnes yr^{-1}) and Mongar (0.38 million tonnes yr^{-1}) have contributed more than 50% of total biomass and carbon increment in Forests in the last five years.

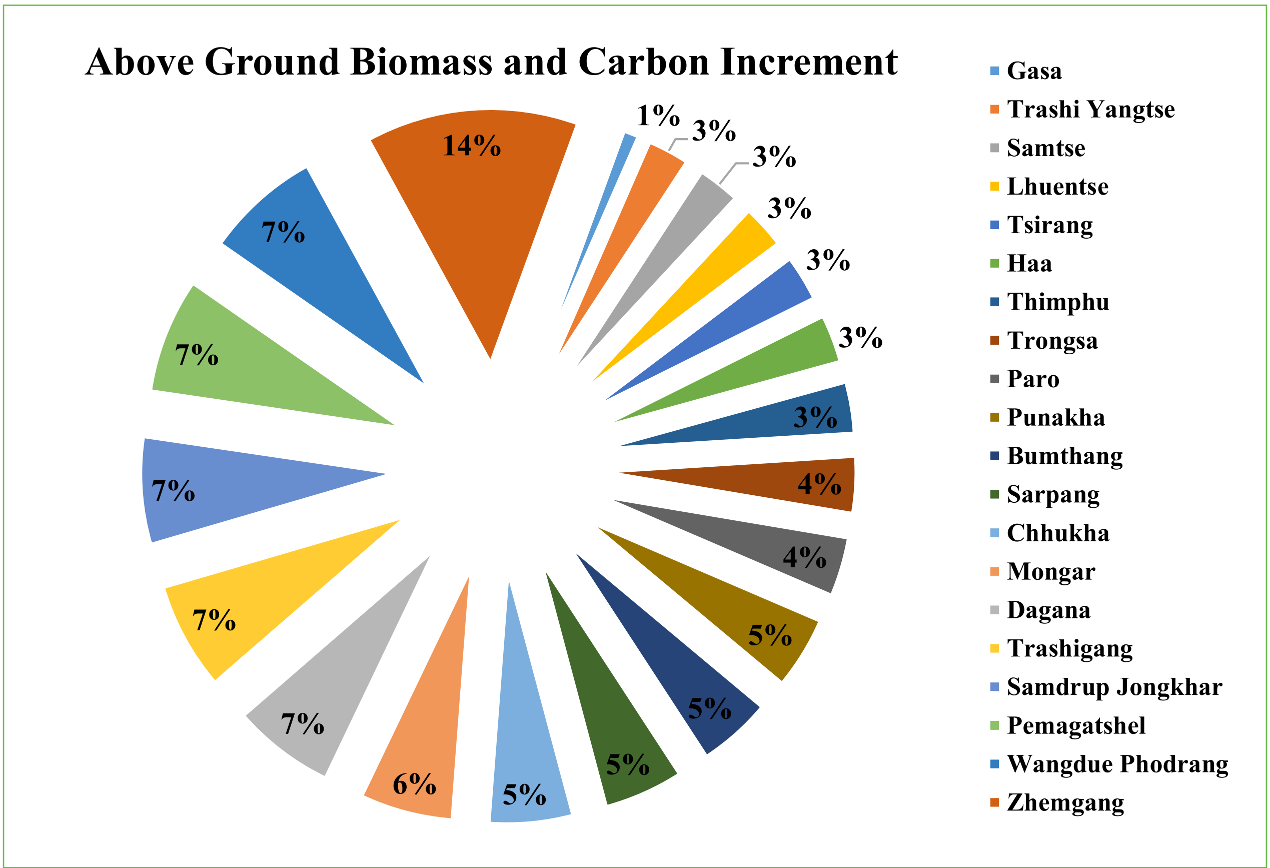

Figure 5.1 Comparison of total biomass increment by Dzongkhag (%)

5.2.3 Biomass and Carbon increment by Forest type

Table 5.4 and Table 5.5 shows the total and per ha estimates for periodic annual biomass and carbon increment in Broadleaved and Coniferous Forests. As evident from the tables, the biomass and carbon increment are greater in Broadleaved Forests as compared to Coniferous Forests.

Table 5.4 Total above-ground biomass and carbon increment by Forest Class (million t)

Forest Class	AGB Increment				AGB Carbon Increment			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	4.64	11.71	4.10	5.19	2.18	11.71	1.93	2.44
Coniferous Forest	1.82	19.29	1.47	2.17	0.85	19.29	0.69	1.02

The carbon increment in Broadleaved Forests is 1.20 tonnes ha^{-1} yr^{-1} which is greater than 1.00 tonnes ha^{-1} yr^{-1} in Coniferous Forest annually in the last five years.

Table 5.5: Above-ground biomass and carbon increment per ha by Forest Class(tonnes ha^{-1} yr^{-1})

Forest Class	AGB Increment				AGB Carbon Increment			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	2.55	11.40	2.26	2.84	1.20	11.40	1.06	1.34
Coniferous Forest	2.12	18.89	1.72	2.52	1.00	18.89	0.81	1.19

Table 5.6 shows the periodic annual biomass and carbon increment in the Forest Types of Bhutan. The carbon increment ranges from 0.27 tonnes ha^{-1} yr^{-1} in the Juniper Rhododendron Forests to 2.46 tonnes ha^{-1} yr^{-1} in the Blue Pine Forests. The carbon increment in Subtropical Forests, Warm Broadleaved Forests, Cool Broadleaved Forests, Blue Pine Forests, Spruce Forests and Hemlock Forests have higher annual carbon increments than annual carbon increments in Forests at the National level.

Warm Broadleaved Forests (0.88 million tonnes yr^{-1}), Cool Broadleaved Forests (0.75 million tonnes yr^{-1}), Subtropical Forests (0.49 million tonnes yr^{-1}) and Fir Forests (0.45 million tonnes yr^{-1}) constitute four fifth (4/5th) of the total carbon increment in the Forests; and the rest of the Forest Types accounts for less than 16% total carbon increment annually for the last five years as shown in Figure 5.2.

Table 5.6: Above-ground biomass and carbon increment by Dzongkhag (tonnes ha^{-1} yr^{-1})

Forest Type	AGB Increment				AGB Carbon Increment			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
STFr	2.94	26.04	2.17	3.70	1.38	26.04	1.02	1.74
CPFr	1.84	51.41	0.89	2.78	0.86	51.41	0.42	1.31
WBFr	2.79	18.06	2.29	3.29	1.31	18.06	1.07	1.55
EOFr	0.77	64.58	0.27	1.27	0.36	64.58	0.13	0.60
CBFr	2.13	14.32	1.82	2.43	1.00	14.32	0.86	1.14
BPFr	3.45	45.05	1.90	5.00	1.62	45.05	0.89	2.35
SPFr	3.20	77.59	0.72	5.69	1.51	77.59	0.34	2.68
HMFr	2.44	39.35	1.48	3.40	1.15	39.35	0.70	1.60
FIFr	2.19	23.61	1.67	2.71	1.03	23.61	0.79	1.27
JRFr	0.58	60.43	0.23	0.93	0.27	60.43	0.11	0.44

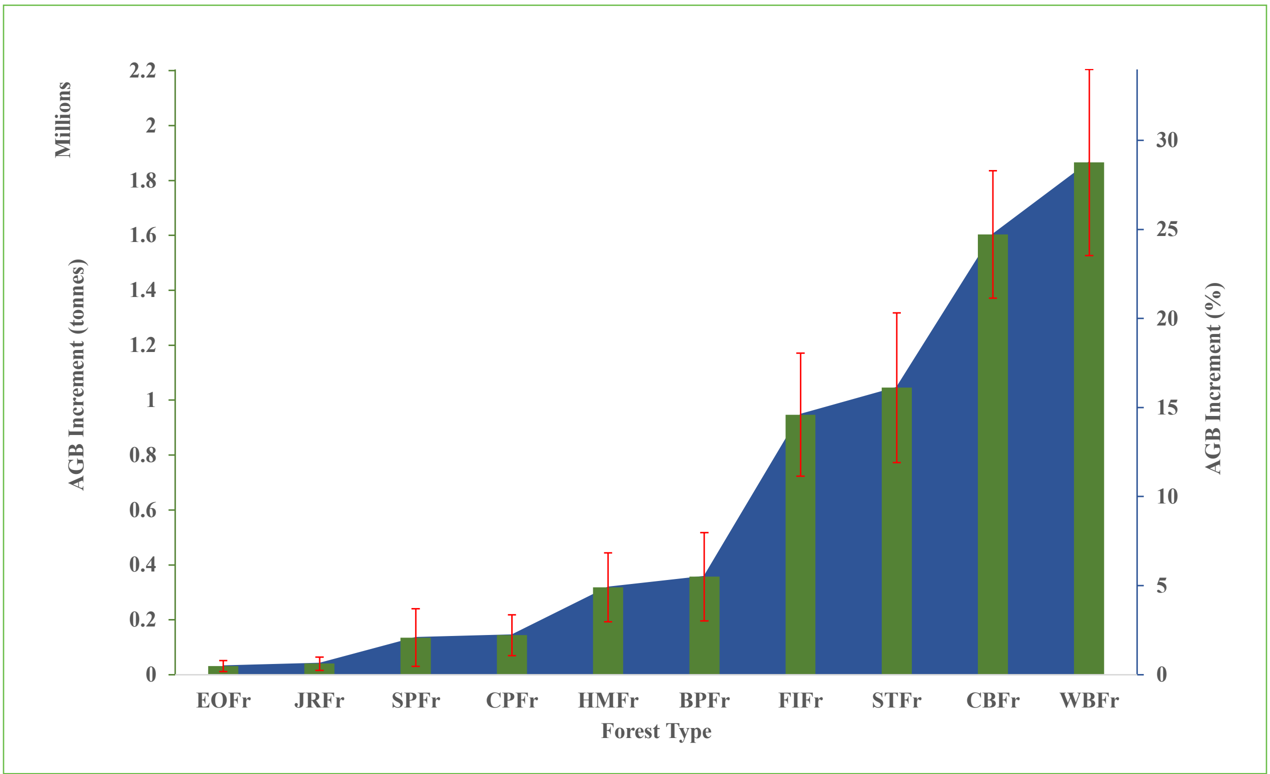

Figure 5.2 Total above-ground biomass and carbon increment by Forest Type

5.2.4 Biomass and Carbon Increment by Elevation

Table 5.7 shows the total periodic annual biomass and carbon increment in different elevation ranges. Total biomass and carbon increment is greatest in the elevation range of 1000 *m.a.s.l* to 2000 *m.a.s.l* and smallest in the highest elevation range of over 4000 *m.a.s.l.*

Table 5.7 Total above-ground biomass and carbon increment by elevation (million tonnes yr^{-1})

Elevation (m.a.s.l)	AGB Increment				AGB Carbon Increment			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
<1000	1.05	27.23	0.76	1.33	0.49	27.23	0.36	0.63
1000-2000	2.12	18.36	1.73	2.51	1	18.36	0.81	1.18
2000-3000	2.06	15.39	1.75	2.38	0.97	15.39	0.82	1.12
3000-4000	1.28	18.72	1.04	1.52	0.6	18.72	0.49	0.71

Figure 5.3 shows the increment per ha per annum by elevation. The increment decreases with increasing elevation. The annual carbon increment decreases from 1.20 tonnes ha^{-1} yr^{-1} in the lowest elevation range to 0.19 tonnes ha^{-1} yr^{-1} in the highest elevation range.

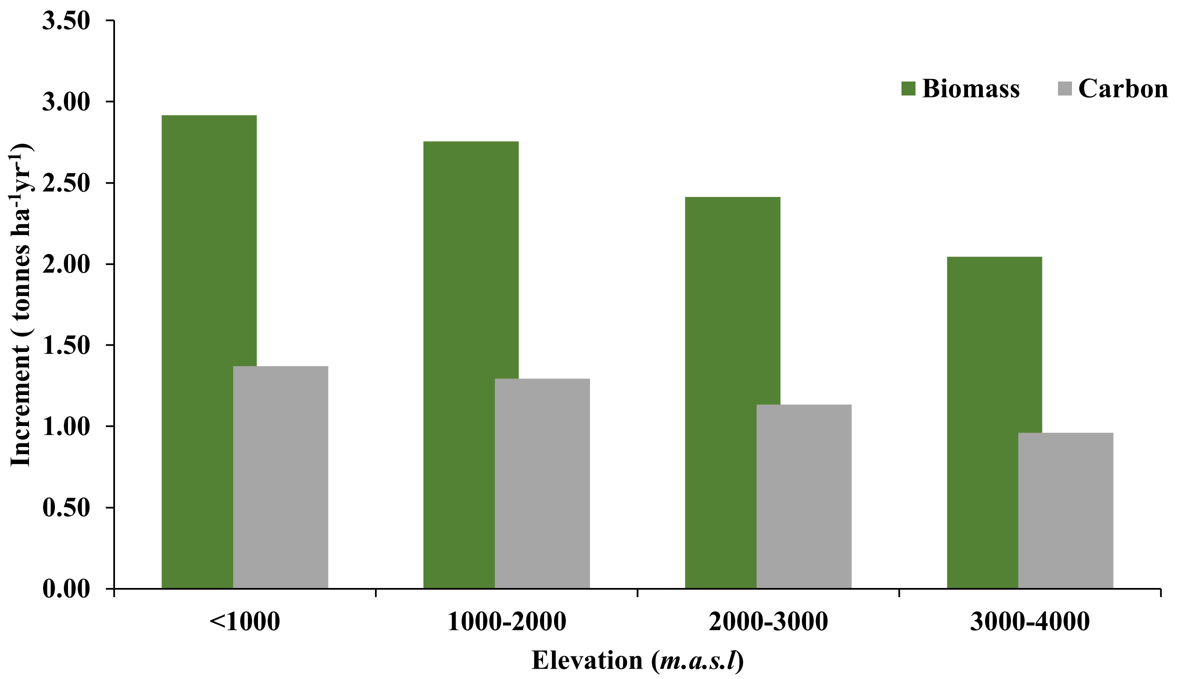

Figure 5.3 Total above-ground biomass increment by Elevation

5.2.5 Biomass and Carbon Increment by Species

Table 5.8 shows the biomass and carbon increment estimates of tree species. *Quercus spp.* has the greatest carbon increment with carbon growth of 0.112 tonnes ha^{-1} yr^{-1}. Similarly, *Quercus spp.* has the greatest total carbon increment of 0.30 million tonnes yr^{-1}, closely followed by *Abies densa* and *Castanopsis spp.* Thirty species contribute 59% of the total biomass and carbon increment in the Forests.

Table 5.8 Above-ground biomass and carbon increment per ha by Species (t $ha^{-1}yr^{-1}$)

Forest Class	AGB Increment				AGB Carbon Increment			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Abies densa	0.164	35.46	0.11	0.22	0.077	35.46	0.05	0.10
Acer spp.	0.058	34.83	0.04	0.08	0.027	34.83	0.02	0.04
Ailanthus integrifolia	0.004	132.07	(0.00)	0.01	0.002	132.07	(0.00)	0.00
Alnus spp.	0.045	70.05	0.01	0.08	0.021	70.05	0.01	0.04
Aphanamixis polystachya	0.003	138.73	(0.00)	0.01	0.002	138.73	(0.00)	0.00
Beilschmiedia spp.	0.044	58.41	0.02	0.07	0.021	58.41	0.01	0.03
Betula spp.	0.051	79.83	0.01	0.09	0.024	79.83	0.00	0.04
Castanopsis spp.	0.122	57.72	0.05	0.19	0.057	57.72	0.02	0.09
Cupressus spp.	0.005	200.00	(0.01)	0.02	0.003	200.00	(0.00)	0.01
Duabanga grandiflora	0.000	200.00	(0.00)	0.00	0.000	200.00	(0.00)	0.00
Engelhardia spicata	0.053	66.87	0.02	0.09	0.025	66.87	0.01	0.04
Exbucklandia populnea	0.016	86.40	0.00	0.03	0.007	86.40	0.00	0.01

Juglans regia	0.005	181.16	(0.00)	0.01	0.002	181.16	(0.00)	0.01
Juniperus spp.	0.033	59.84	0.01	0.05	0.016	59.84	0.01	0.03
Larix griffithii	0.002	191.39	(0.00)	0.01	0.001	191.39	(0.00)	0.00
Magnolia spp.	0.013	82.23	0.00	0.02	0.006	82.23	0.00	0.01
Persea spp.	0.079	31.99	0.05	0.10	0.037	31.99	0.03	0.05
Phoebe goalparensis	0.002	143.83	(0.00)	0.00	0.001	143.83	(0.00)	0.00
Picea spinulosa	0.046	67.26	0.02	0.08	0.022	67.26	0.01	0.04
Pinus roxburghii	0.027	85.86	0.00	0.05	0.013	85.86	0.00	0.02
Pinus wallichiana	0.114	71.39	0.03	0.20	0.054	71.39	0.02	0.09
Quercus spp.	0.238	43.93	0.13	0.34	0.112	43.93	0.06	0.16
Rhododendron spp.	0.108	30.37	0.08	0.14	0.051	30.37	0.04	0.07
Schima wallichii	0.053	44.48	0.03	0.08	0.025	44.48	0.01	0.04
Sterculia villosa	0.003	200.00	(0.00)	0.01	0.002	200.00	(0.00)	0.00
Symplocos spp.	0.043	36.80	0.03	0.06	0.020	36.80	0.01	0.03
Taxus baccata	0.005	131.19	(0.00)	0.01	0.003	131.19	(0.00)	0.01
Terminalia myriocarpa	0.004	200.00	(0.00)	0.01	0.002	200.00	(0.00)	0.01
Tetrameles nudiflora	0.012	200.00	(0.01)	0.04	0.006	200.00	(0.01)	0.02
Tsuga dumosa	0.059	66.14	0.02	0.10	0.028	66.14	0.01	0.05
Others	0.983	14.26	0.84	1.12	0.462	14.26	0.40	0.53

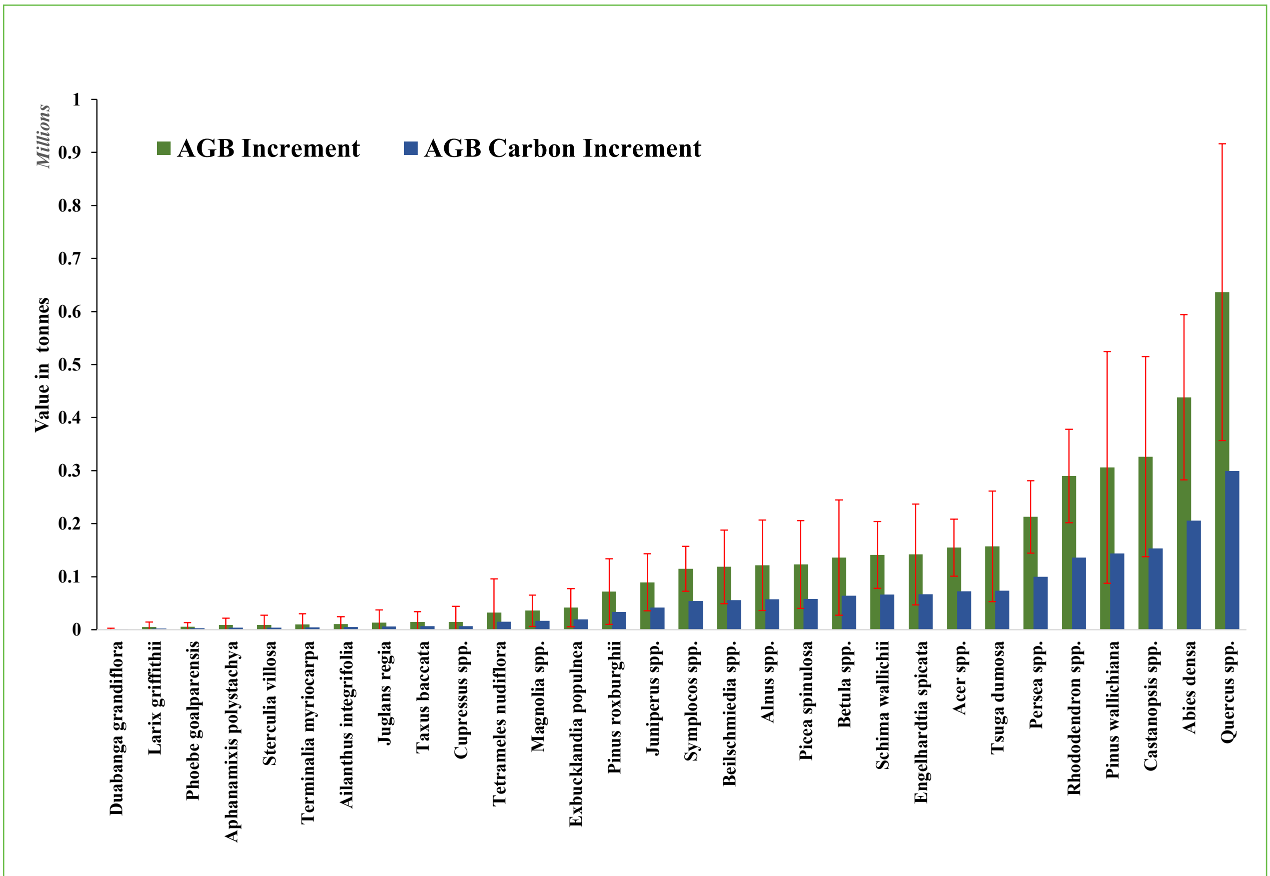

Figure 5.4 Total above-ground biomass and carbon increment by Species

5.3 Carbon Sequestration

5.3.1 Background

Carbon sequestration is the process of the removal of carbon dioxide from the atmosphere and storing it in the form of biomass/carbon in plants, soils, geologic formations, and the ocean. Forests play an important role in climate change mitigation through sequestration of atmospheric carbon and storing in the form of biomass. The carbon sequestration potential of the Forest is determined by the process-based method and stock change method (IPCC 2006). However, full accounting of emissions and removals is not within the scope of this report. Therefore, only total carbon sequestration is estimated and reported, emission resulting from Forest related activities and other sector are not included in the report. The carbon sequestration potential is estimated using the equation (5.2) (IPCC, 2006) based on the biomass growth estimated using the tree ring analysis.

$$CS_F = A_F \times BG_F \times CF \times \frac{44}{12}$$

(5.2)

Where,

CS_F is the total carbon sequestration, (t CO_2 yr-1);

A_F is area of Forest, ha;

BG_F is Biomass growth in Forest, (t d.m ha-1yr-1);

CF is Carbon fraction; and

44/12 is the CO_2 fraction.

5.3.2 Carbon Sequestration by Land Class

Table 5.9 and Table 5.10 shows the total carbon sequestration and carbon sequestration rate in Forest and Non-Forest land. The total carbon sequestration in Forest is 11 million tonnes of CO_2 per year with sequestration rate of 4.18 tonnes CO_2 ha^{-1} yr^{-1}. The carbon sequestration rate (1.66 tonnes CO_2 ha^{-1} yr^{-1}) and total carbon sequestration (2 million tonnes yr^{-1}) in Non-Forest land is smaller compared to the Forest land.

Table 5.9 Total Carbon Sequestration by Land Class

Land Class	CO_2 (tonnes yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Forest	11,186,067.42	9.97	1,115,403.02	10,070,664.41
Non-Forest	1,926,640.73	64.35	1,239,707.78	686,932.95

Table 5.10 Carbon sequestration Rate by Land Class

Land Class	CO_2 (tonnes ha^1 yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Forest	4.18	9.80	3.77	4.59
Non-Forest	1.66	64.32	0.59	2.72

5.3.3 Carbon Sequestration by Dzongkhag

Table 5.11 and Table 5.12 shows carbon sequestration rate and total carbon sequestration by Dzongkhag. Carbon sequestration rate varies significantly among the Dzongkhags. Pemagatshel Dzongkhag has the greatest carbon sequestration rate (9.12 tonnes CO_2 ha^{-1} yr^{-1}) and Gasa Dzongkhag has the smallest carbon sequestration rate (1.68 tonnes CO_2 ha^{-1} yr^{-1}). Total carbon sequestration is greatest in Zhemgang Dzongkhag (1.49 million tonnes CO_2) and smallest in Gasa Dzongkhag (0.11 million tonnes CO_2).

Table 5.11 Carbon Sequestration Rate by Dzongkhag

Dzongkhag	CO_2 (tonnes ha^{-1} yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Bumthang	3.65	35.70	1.95	4.56
Chhukha	3.62	51.10	10.63	14.33
Dagana	4.69	22.02	2.00	4.06
Gasa	1.68	34.62	0.22	1.38
Haa	2.75	35.69	0.85	2.81
Lhuentse	1.70	69.13	(-1.11)	1.25
Mongar	3.80	57.36	2.63	6.99
Paro	5.61	43.96	(-1.59)	3.34
Pemagatshel	9.12	70.12	2.03	14.82
Punakha	5.75	37.19	4.66	8.93
Samdrup Jongkhar	4.38	30.55	3.43	6.11
Samtse	2.99	25.59	1.78	3.31
Sarpang	3.85	22.79	4.50	6.25
Thimphu	4.43	29.94	1.94	4.59
Trashigang	4.63	25.87	1.44	3.83
Trashi Yangtse	3.59	44.64	1.34	4.54
Trongsa	2.73	38.81	(-0.85)	1.26
Tsirang	5.95	44.56	0.93	6.23
Wangdue Phodrang	3.14	23.14	1.48	2.94
Zhemgang	6.67	32.91	5.36	9.75

Table 5.12 Total Carbon Sequestration by Dzongkhag

Dzongkhag	CO_2 (million tonnes yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Bumthang	518,615.45	36.53	329,182.66	708,048.25
Chhukha	589,573.42	51.39	286,610.21	892,536.63
Dagana	718,722.61	22.74	555,280.77	882,164.45
Gasa	110,286.39	35.09	71,588.38	148,984.40
Haa	340,057.01	36.74	215,131.88	464,982.14
Lhuentse	306,031.17	69.50	93,344.59	518,717.75
Mongar	650,284.53	57.62	275,594.80	1,024,974.25
Paro	419,152.62	45.30	229,258.87	609,046.36
Pemagatshel	808,756.57	70.56	238,086.77	1,379,426.36

Punakha	509,774.94	38.40	314,020.13	705,529.75
Samdrup Jongkhar	754,310.70	30.98	520,594.89	988,026.50
Samtse	298,240.91	27.17	217,195.33	379,286.48
Sarpang	558,484.53	23.66	426,335.39	690,633.67
Thimphu	361,567.46	31.36	248,178.85	474,956.07
Trashigang	753,872.94	26.91	551,011.53	956,734.35
Trashi Yangtse	293,859.47	45.84	159,156.12	428,562.83
Trongsa	400,060.83	39.48	242,121.49	558,000.17
Tsirang	323,456.18	46.12	174,265.71	472,646.65
Wangdue Phodrang	812,930.33	23.91	618,573.44	1,007,287.22
Zhemgang	1,487,986.65	33.14	994,805.97	1,981,167.34

5.3.4 Carbon Sequestration by Forest Type

Table 5.13 and Table 5.14 shows the carbon sequestration rate and total carbon sequestration in Broadleaved and Coniferous Forests. Both carbon sequestration rate and total carbon sequestration is greater in Broadleaved Forest in comparison to Coniferous Forest. The carbon sequestration rate in Broadleaved Forest is 4.40 tonnes CO_2 ha^{-1} yr^{-1} while the Coniferous Forest has a carbon sequestration rate of 3.66 tonnes CO_2 ha^{-1} yr^{-1}.

Table 5.13 Carbon Sequestration Rate by Foerst Class

Forest Class	CO2 (tonnes ha^{-1} yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	4.40	11.40	3.90	4.90
Coniferous Forest	3.66	18.89	2.97	4.35

Table 5.14 Total Carbon Sequestration by Forest Class

Forest Class	CO_2 (tonnes yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	8,001,353.86	11.71	7,064,266.65	8,938,441.07
Coniferous Forest	3,134,014.63	19.29	2,529,604.41	3,738,424.86

5.4 Discussion

Forests play a vital role in climate change mitigation through the process of carbon sequestration. The rate of carbon sequestration is directly dependent on rate of biomass growth (Chen et al., 2023). Forests with greater biomass growth have greater potential to sequester carbon compared to the Forests with a lower biomass growth rate. The annual biomass increment of Forests is estimated to be 2.43 ±0.24 tonnes of biomass ha^{-1} yr^{-1} (1.13 ±0.11 tonnes of carbon ha^{-1} yr^{-1}) which is slightly greater than the estimates reported in the 1st NFI (2.01 ±0.22 tonnes of biomass ha^{-1} yr^{-1}) (FRMD, 2018b). Biomass increment has increased annually by 0.84 % which is greater than the global carbon stock increment of 0.06% (Xu et al., 2021) and the average carbon stock increment of 0.03% in the five East Asian countries of China, Japan, North Korea, South Korea and Mongolia (Fang et al., 2014). The increase in annual biomass increment may be attributed to improved Forest management (Krug, 2019) and an increased number of trees with smaller DBH as biomass growth in smaller diameter trees are greater than the large diameter trees (Forrester, 2021).

Pemagatshel Dzongkhag has the greatest annual carbon increment 2.49.13 ±1.74 tonnes ha^{-1} yr^{-1}. This is closely followed by the Zhemgang and Tsirang Dzongkhags which mostly have Broadleaved Forests; which has greater basal area increments compared to Coniferous Forest. Basal area is strongly correlated with biomass accumulation (Osei, 2022), which differs by the type of Forest found in the regions in addition to other environmental factors.

The average biomass increment in Broadleaved Forests (2.55 ± 0.29 ha^{-1} yr^{-1}) is greater than the annual biomass accumulation in Coniferous Forests (2.12 ± 0.40 tonnes ha^{-1} yr^{-1}). Greater biomass accumulation in Broadleaved Forests than the Coniferous Forests were observed in the United States (Brown, 2001) and, similarly, studies in Europe (Osei et al., 2022) saw greater biomass accumulation in Broadleaved species than in Scots Pine. However, the greatest annual biomass accumulation is recorded in Blue Pine Forests (3.45 ± 1.55 tonnes ha^{-1} yr^{-1}) followed by Spruce Forests (3.20 ± 2.49 tonnes ha^{-1} yr^{-1}). The greater biomass accumulation in the Blue Pine and Spruce may be attributed to climate change which lead to increase in mean annual temperatures since the mean annual temperature has a positive correlation with AGB accumulation in Pine Forest (Chen et al., 2023).

The biomass increment shows a negative correlation with elevation, with the increment decreasing with the increase in elevation. The greatest increment is estimated to be in the elevation ranges of 0 -1000 m.a.s.l with annual biomass increment of 2.92 ± 0.78 tonnes ha^{-1} yr^{-1} and smallest in the elevation range of over 4000 m.a.s.l with 0.40 ± 0.25 tonnes ha^{-1} yr^{-1}. This shows that the trees in the lower elevations are accumulating more biomass than the trees in the greater elevations. This may be attributed to the lower temperature at greater elevations which impedes tree growth (Rai et al., 2018).

Biomass accumulation is affected by the species composition and structure (Baul et al., 2021; Chen et al., 2023). Accordingly, the biomass accumulation varies significantly among the species, with increments ranging from 0.000365 tonnes ha^{-1} yr^{-1} to 0.238 tonnes ha^{-1} yr^{-1}. *Quercus spp.* has the greatest biomass growth of 0.238 tonnes ha^{-1} yr^{-1} (0.112 t C ha^{-1} yr^{-1}). In general, most of the Broadleaved species have greater biomass accumulation compared to the Coniferous species. While there are contrasting theories on the relationship between carbon sequestration and biodiversity (Lecina-Diaz et al., 2018; Van De Perre et al., 2018), there is, in general, a positive correlation between carbon sequestration and species diversity (Baul et al., 2021; Cardinale et al., 2007; Lecina-Diaz et al., 2018; Van De Perre et al., 2018). Therefore, the high biomass accumulation in *Quercus* and other broadleaved species may be attributed to greater diversity in Broadleaved Forests as Oaks are generally found mixed with other Broadleaved species.

The biomass carbon density increases with elevation and peaks around 2000-3000 *m.a.s.l*. It ranges from 45.93 tonnes ha^{-1}in elevations below 1000 *m.a.s.l* and 163.07 tonnes ha^{-1} in 2000-3000 *m.a.s.l.* SOC density is 32.4 tonnes ha^{-1} below 1000 *m.a.sl,* which increases with increase in elevation to a maximum of 92.10 tonnes ha^{-1} between 3000 to 4000 *m.a.s.l.* This variation is consistent with other studies. For example, Tashi et al. (2016) found increased carbon density with elevation from Phuentsholing to Gedu; Simon et al. (2018) found similar relationship in the Temperate Coniferous Forest of central and western Bhutan.

The biomass carbon density decreased across all elevation ranges in comparison to 1st NFI (FRMD, 2018) while SOC density decreased in the elevation ranges of less than 1000 *m.a.s.l* and 1000-2000 *m.a.s.l.* However, there is a marginal increase in SOC density between 2000-3000 *m.a.s.l* and 3000 – 4000 *m.a.s.l.* The decrease in biomass carbon density may be attributed to the use of more species-specific biomass equations and differences in computational methods. However, the increase or decrease in SOC density by elevation requires further investigation by increasing the number of samples.

The total carbon sequestration of Forest is estimated to be 11 million tonnes of CO_2 per annum in 2022 and it is an increase of 1.6 million tonnes of CO_2 per year from 9.4 million tonnes of CO_2 per year recorded in 2015. However, this estimate does not include carbon emission from Forest such as deforestation, timber harvesting, Forest fires and firewood collection; and emission from other sectors such as energy and transport, industries, waste and agriculture and livestock.

The average carbon sequestration rate in Pemagatshel (9.12 tonnes CO_2 ha^{-1} yr^{-1}), Zhemgang (6.67 tonnes CO_2 ha^{-1} yr^{-1}), Tsirang (5.95 tonnes CO_2 ha^{-1} yr^{-1}), Punakha (5.75 tonnes CO_2 ha^{-1} yr^{-1}), Paro (5.61 tonnes CO_2 ha^{-1} yr^{-1}), Dagana (4.69 tonnes CO_2 ha^{-1} yr^{-1}), Trashigang (4.63 tonnes CO_2 ha^{-1} yr^{-1}), Thimphu (4.43 tonnes CO_2 ha^{-1} yr^{-1}) and Samdrup Jongkhar (4.38 tonnes CO_2 ha^{-1} yr^{-1}) Dzongkhag are greater than the average carbon sequestration rate in Forests.

Broadleaved Forest sequesters more carbon (4.4 tonnes CO_2 ha^{-1} yr^{-1}) than the Coniferous Forest (3. 66 tonnes CO_2 ha^{-1} yr^{-1}) annually. This show that the carbon sequestration is greater in lower altitude than in higher altitude as Broadleaved Forest is found in lower region compared to Coniferous Forest.

6 WAY FORWARD

The biomass and carbon estimates reported in this report are based on the data collected from the NFI. The NFI has 2,424 CP, and 20 % of the CP (485 CP) were randomly selected as *"carbon plots"* for collection of the understorey above-ground shrubs, herbs, litter and SOC. However, only 1,969 cluster plots were accessible and accordingly, only above-ground shrubs, herbs, litter and SOC data could be collected from 354 *"carbon plots"*. The inaccessibility of 455 CP may have contributed significantly to the accuracy and precision of the estimates reported in this report. Therefore, as highlighted in the *National Forest Inventory Report Volume I: State of Forest Report,* the precision of the estimates is high at the National and Dzongkhag levels, however, further intensified studies in smaller reporting units such as *Gewogs* or *Chiwogs* may provide more accurate estimates. Some of the findings and recommendations from this NFI are:

General

- There are limited methods for estimating the biomass and carbon of fine woody debris (FWD). Application of the estimation method for CWD greatly overestimates/ underestimates the biomass of FWD. The estimation method for CWD and FWD needs to be studied at smaller units and then replicated in the future NFIs.
- Data on living and dead stumps were not collected and therefore, no biomass and carbon estimates are made for these components of living and dead carbon pools.
- The NFI design records only the presence and absence data for Bamboos and Canes, hence, could not be used to estimate their biomass. Future NFIs should consider collection of disaggregated data of Bamboos and Canes for reporting their biomass.
- Estimates of the 1st NFI and current NFI are in many cases incomparable due to computational differences resulting in huge differences in the estimates. Therefore, a standard estimation procedure may be developed for the purpose of consistency.
- NFI may consider the collection of DBH or diameter at the collar region for woody shrubs in the future to account for the biomass and carbon for the woody shrubs. And, accordingly develop allometric biomass equations for shrubs.
- Biomass of dead tress were not estimated separately.

Assignment of Forest Type

- There are differences in the assignment of Forest Types, and Forests & Non-Forests between categories. The NFI field manual may be revised during which the Forest and Forest Type interpretation guidelines can be developed.

Growth and Increment

- Biomass and carbon increments are estimated using 4,127 tree cores only and would have resulted in over or underestimation of the increment. Future NFIs may consider collection of additional cores or use the stock change method of carbon accounting for the estimation of increment.
- The increment reported here does not account for the wood harvested. Reporting in the future should consider including gross as well as the net increments.

- While the NFI is conducted on permanent sample plots, it is difficult to directly compare the tree-to-tree and plot-to-plot data for the 1st and 2nd NFIs as plot centers of the 1st NFI could not be located for re-measurement. Therefore, future inventories should attempt relocation of the plot center and re-measurement of each plot and trees, which are tagged with uniquely numbered tree tags.

Understorey Above Ground Biomass, Litter and Soil samples

- Understorey carbon samples are designed to be collected from about 20% of the total plots. The actual sample size is smaller owing to the inaccessibility of the plots. Future inventories may consider collecting samples from all the plots or stratifying the sample collection by Land categories and Forest Types.
- Review the sampling design for soil and litter samples and study the feasibility of collection of samples from all the plots or stratification of the sample locations.
- Soil samples take a considerable amount of time to reach the laboratory for chemical analysis. A SOP or framework should be developed to enable the delivery of samples within a few days from the date/day of collection.

Forest Disturbances

- Forest disturbances have both positive and negative impacts on biomass accumulation. Therefore, independent investigations are recommended in order to study the impacts of Forest disturbances on biomass losses and accumulation.

NFI Data management

- The 2nd NFI uses the *Open Foris* tool of the FAO for data collection and data management. However, the major limitation of this software package is that there is no provision to update the data from a different inventory cycle. Therefore, it is important to develop an NFI database with basic analytical features.

The NFI is a very resource intensive activity, both financially as well as in terms of human resources/ manpower. Therefore, it may be institutionalized as a part of the regular activities of the Department through the review of the data parameters and integration of the NFI with Forest management inventories. This shall save the Department time and money, in addition to the collection of quality data. Furthermore, it is also recommended to include a social component in the future NFIs.

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8 APPENDICES

Chapter 3: Forest Biomass and Carbon

1. Total Carbon estimate at National Level

Land Class	Carbon (tonnes per ha)	MoE (%)	Total Carbon (million tonnes)	MoE (%)
Bhutan	268.95	4.46	609.02	3.91
Forest	195.73	3.89	523.87	4.04
Non-Forest	73.22	12.68	85.15	12.77

2. Biomass and Carbon estimate for Non-Forest

Carbon Pool	Carbon Pool Compo-nent	Biomass				Carbon			
		Biomass (tonnes per ha)	MoE (%)	Total (million tonnes)	MoE (%)	Carbon (tonnes per ha)	MoE (%)	Total (million tonnes)	MoE (%)
AGB	Tree	8.69	27.37	10.11	27.44	4.09	27.37	4.75	27.44
	Sapling	0.92	57.32	1.07	57.35	0.43	57.32	0.50	57.35
	Shrub	2.51	50.74	2.91	50.78	1.18	50.74	1.37	50.78
	Herb	0.51	27.81	0.59	27.87	0.24	27.81	0.28	27.87
BGB	Tree	2.65	24.75	3.08	24.82	1.25	24.75	1.45	24.82
	Sapling	0.92	57.32	1.07	57.35	0.43	57.32	0.50	57.35
DOM	CWD	0.27	112.74	0.31	112.76	0.12	112.74	0.15	112.76
	Litter	15.54	38.14	18.07	38.18	7.31	38.13	8.50	38.17
Soil	Soil (0-30 cm depth)					58.18	15.05	67.65	15.16
Total Estimate						73.22	12.68	85.15	12.77

3. Above-ground Biomass (AGB) Carbon

(i) Total estimate for AGB and AGB Carbon by Land Cover

Land Class	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	509.39	6.31	477.27	541.5	239.41	6.31	224.32	254.51
Non-Forest	10.11	27.44	7.34	12.88	4.75	27.44	3.45	6.06

(ii) AGB and AGB Carbon per ha by Land Class

Land Cover	AGB (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	190.31	6.02	178.85	201.78	89.45	6.02	84.06	94.83
Non-Forest	8.69	27.37	6.31	11.07	4.09	27.37	2.97	5.2

3.1 *Tree AG Biomass and AGB Carbon*

(i) Total estimate for Tree AG Biomass and Carbon by Land Class

Land Cover	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	509.39	6.31	477.27	541.50	239.41	6.31	224.32	254.51
Non-Forest	10.11	27.44	7.34	12.88	4.75	27.44	3.45	6.06

(ii) Tree AG Biomass and Carbon per ha by Land Cover

Land Cover	AGB (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	190.31	6.02	178.85	201.78	89.45	6.02	84.06	94.83
Non-Forest	8.69	27.37	6.31	11.07	4.09	27.37	2.97	5.20

(iii) Tree AG Biomass and Carbon per ha by Species

Species	AGB (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Abies densa	26.42	14.82	22.51	30.34	12.42	14.82	10.58	14.26
Acer spp.	4.56	13.35	3.96	5.17	2.15	13.35	1.86	2.43
Ailanthus integrifolia	0.18	71.77	0.05	0.30	0.08	71.77	0.02	0.14
Alnus spp.	1.91	25.59	1.42	2.40	0.90	25.59	0.67	1.13
Aphanamixis polystachya	0.33	47.05	0.18	0.49	0.16	47.05	0.08	0.23
Beilschmiedia spp.	1.95	26.10	1.44	2.45	0.91	26.10	0.68	1.15
Betula spp.	3.37	16.94	2.80	3.94	1.58	16.94	1.31	1.85
Bombax ceiba	0.15	81.12	0.03	0.27	0.07	81.12	0.01	0.13
Castanopsis spp.	8.74	16.70	7.28	10.20	4.11	16.70	3.42	4.79
Cupressus spp.	0.53	169.83	(0.37)	1.43	0.25	169.83	(0.17)	0.67
Duabanga grandiflora	0.39	41.44	0.23	0.56	0.18	41.44	0.11	0.26
Engelhardtia spicata	1.61	25.39	1.20	2.02	0.76	25.39	0.56	0.95
Exbucklandia populnea	1.00	59.18	0.41	1.59	0.47	59.18	0.19	0.75
Juglans regia	0.23	54.75	0.10	0.36	0.11	54.75	0.05	0.17
Juniperus spp.	2.21	34.17	1.45	2.96	1.04	34.17	0.68	1.39
Larix griffithii	0.16	64.49	0.06	0.27	0.08	64.49	0.03	0.12
Magnolia spp.	2.03	27.10	1.48	2.58	0.95	27.10	0.70	1.21
Persea spp.	8.36	15.13	7.10	9.63	3.93	15.13	3.34	4.53
Phoebe goalparensis	0.16	74.12	0.04	0.28	0.07	74.12	0.02	0.13
Picea spinulosa	2.70	36.09	1.73	3.68	1.27	36.09	0.81	1.73
Pinus roxburghii	2.85	31.47	1.95	3.75	1.34	31.47	0.92	1.76
Pinus wallichiana	4.46	28.73	3.18	5.74	2.10	28.73	1.49	2.70
Quercus spp.	31.56	11.65	27.89	35.24	14.84	11.65	13.11	16.56

Rhododendron spp.	7.83	13.25	6.80	8.87	3.68	13.25	3.19	4.17
Schima wallichii	2.15	23.15	1.65	2.64	1.01	23.15	0.78	1.24
Sterculia villosa	0.32	49.28	0.16	0.48	0.15	49.28	0.08	0.23
Symplocos spp.	7.20	124.45	(1.76)	16.16	3.38	124.45	(0.83)	7.60
Taxus baccata	0.57	42.90	0.33	0.82	0.27	42.90	0.15	0.38
Terminalia myriocarpa	0.42	60.09	0.17	0.67	0.20	60.09	0.08	0.32
Tetrameles nudiflora	0.65	63.40	0.24	1.07	0.31	63.40	0.11	0.50
Tsuga dumosa	7.11	24.29	5.38	8.84	3.34	24.29	2.53	4.15
Others	58.15	6.09	54.61	61.69	27.33	6.09	25.66	28.99

(iv) Total biomass and carbon estimates in million tonnes by DBH Class

DBH Class (cm)	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
10-20	42.02	7.55	38.85	45.19	19.75	7.55	18.26	21.24
20-30	43.81	4.70	41.75	45.87	20.59	4.70	19.62	21.56
30-40	46.72	4.29	44.72	48.72	21.96	4.29	21.02	22.90
40-50	47.34	4.73	45.10	49.58	22.25	4.73	21.20	23.30
50-60	48.62	5.72	45.84	51.41	22.85	5.72	21.55	24.16
60-70	47.29	6.34	44.29	50.29	22.23	6.34	20.82	23.63
70-80	43.88	7.40	40.63	47.13	20.62	7.40	19.10	22.15
80-90	44.28	9.33	40.15	48.41	20.81	9.33	18.87	22.75
90-100	33.52	10.42	30.03	37.02	15.76	10.42	14.11	17.40
100-110	22.07	13.93	18.99	25.14	10.37	13.93	8.93	11.82
110-120	21.90	15.31	18.55	25.26	10.29	15.31	8.72	11.87
120-130	15.89	19.17	12.84	18.94	7.47	19.17	6.04	8.90
130-140	22.15	108.34	(1.85)	46.15	10.41	108.34	(0.87)	21.69
140-150	8.68	26.62	6.37	10.99	4.08	26.62	2.99	5.17
150-160	6.70	34.86	4.36	9.03	3.15	34.86	2.05	4.24
160-170	3.21	57.23	1.37	5.05	1.51	57.23	0.65	2.37
170-180	2.90	56.35	1.26	4.53	1.36	56.35	0.59	2.13
180-190	2.19	64.87	0.77	3.61	1.03	64.87	0.36	1.70
>=190	6.22	56.84	2.68	9.75	2.92	56.84	1.26	4.58

(v) Total biomass and carbon estimates by Height Class

Height Class (m)	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
<5	3.94	18.58	3.20	4.67	1.85	18.58	1.51	2.19
5-10	46.68	7.51	43.18	50.19	21.94	7.51	20.29	23.59
10-15	99.41	24.45	75.11	123.72	46.72	24.45	35.30	58.15
15-20	105.60	5.95	99.32	111.89	49.63	5.95	46.68	52.59

20-25	105.25	7.17	97.71	112.80	49.47	7.17	45.92	53.02
25-30	75.69	8.98	68.89	82.49	35.57	8.98	32.38	38.77
30-35	39.40	12.79	34.37	44.44	18.52	12.79	16.15	20.89
35-40	18.87	17.54	15.56	22.18	8.87	17.54	7.31	10.43
>= 40	14.53	27.65	10.51	18.55	6.83	27.65	4.94	8.72

3.2 Sapling AGB

(i) Total estimates for Sapling AGB and AGB Carbon by Land Class

Land Cover	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	9.21	41.51	5.39	13.03	4.33	41.51	2.53	6.12
Non-Forest	1.07	57.35	0.46	1.69	0.50	57.35	0.21	0.79

(ii) Sapling AGB and AGB Carbon per ha by Land Class

Land Cover	AGB (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	3.44	41.47	2.01	4.87	1.62	41.47	0.95	2.29
Non-Forest	0.92	57.32	0.39	1.45	0.43	57.32	0.18	0.68

(iii) Sapling AGB and AGB Carbon per ha by species

Species	Above Ground Biomass				Above Ground Biomass Carbon			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Abies densa	0.05	37.52	0.03	0.07	0.02	37.52	0.02	0.03
Acer spp.	0.31	177.20	(0.24)	0.87	0.15	177.20	(0.11)	0.41
Ailanthus integrifolia	0.00	95.09	0.00	0.01	0.00	95.09	0.00	0.00
Alnus spp.	0.02	79.56	0.00	0.03	0.01	79.56	0.00	0.01
Aphanamixis polystachya	0.01	46.83	0.01	0.01	0.00	46.83	0.00	0.01
Beilschmiedia spp.	0.01	31.28	0.01	0.02	0.01	31.28	0.00	0.01
Betula spp.	0.05	54.34	0.02	0.07	0.02	54.34	0.01	0.03
Bombax ceiba	0.00	160.55	(0.00)	0.00	0.00	160.55	(0.00)	0.00
Castanopsis spp.	0.08	26.37	0.06	0.10	0.04	26.37	0.03	0.05
Cupressus spp.	0.00	141.83	(0.00)	0.00	0.00	141.83	(0.00)	0.00
Duabanga grandiflora	0.00	124.69	(0.00)	0.00	0.00	124.69	(0.00)	0.00
Engelhardtia spicata	0.02	35.26	0.01	0.03	0.01	35.26	0.01	0.01
Exbucklandia populnea	0.00	56.82	0.00	0.01	0.00	56.82	0.00	0.00
Juglans regia	0.00	77.88	0.00	0.00	0.00	77.88	0.00	0.00
Juniperus spp.	0.02	50.61	0.01	0.03	0.01	50.61	0.00	0.01
Larix griffithii	0.00	125.14	(0.00)	0.00	0.00	125.14	(0.00)	0.00

Magnolia spp.	0.00	46.57	0.00	0.01	0.00	46.57	0.00	0.00
Persea spp.	0.07	19.99	0.06	0.09	0.03	19.99	0.03	0.04
Phoebe goalparensis	0.00	77.69	0.00	0.00	0.00	77.69	0.00	0.00
Picea spinulosa	0.00	47.92	0.00	0.01	0.00	47.92	0.00	0.00
Pinus roxburghii	0.03	50.01	0.02	0.05	0.02	50.01	0.01	0.02
Pinus wallichiana	0.05	47.42	0.03	0.08	0.02	47.42	0.01	0.04
Quercus spp.	0.17	22.15	0.13	0.20	0.08	22.15	0.06	0.10
Rhododendron spp.	1.04	90.14	0.10	1.97	0.49	90.14	0.05	0.93
Schima wallichii	0.03	35.33	0.02	0.04	0.01	35.33	0.01	0.02
Sterculia villosa	0.00	60.34	0.00	0.00	0.00	60.34	0.00	0.00
Symplocos spp.	0.22	16.32	0.19	0.26	0.10	16.32	0.09	0.12
Taxus baccata	0.00	150.47	(0.00)	0.00	0.00	150.47	(0.00)	0.00
Terminalia myriocarpa	0.00	77.14	0.00	0.00	0.00	77.14	0.00	0.00
Tetrameles nudiflora	0.00	164.90	(0.00)	0.00	0.00	164.90	(0.00)	0.00
Tsuga dumosa	0.01	59.74	0.00	0.01	0.00	59.74	0.00	0.01
Others	1.37	7.60	1.26	1.47	0.64	7.60	0.59	0.69

3.3 Shrub

(i) Total AG biomass and carbon estimation in shrub by Land Class

Land Cover	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	3.68	21.19	2.90	4.47	1.73	21.19	1.36	2.10
Non-Forest	2.91	50.78	1.43	4.39	1.37	50.78	0.67	2.07

(ii) Shrub biomass and carbon per ha by Land Cover

Land Cover	AGB (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	1.38	21.11	1.09	1.67	0.65	21.11	0.51	0.78
Non-Forest	2.51	50.74	1.23	3.78	1.18	50.74	0.58	1.78

3.4 Herb

(i) Total biomass and carbon estimation in herb by Land Class

Land Cover	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	1.13	24.45	0.85	1.40	0.53	24.45	0.40	0.66
Non-Forest	0.59	27.87	0.43	0.75	0.28	27.87	0.20	0.35

(ii) Herb biomass and carbon per ha by Land Class

Land Cover	AGB (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	0.42	24.38	0.32	0.52	0.20	24.38	0.15	0.25
Non-Forest	0.51	27.81	0.37	0.65	0.24	27.81	0.17	0.30

4. Below-ground Biomass (BGB)

4.1 Tree BGB

(i) Total estimates for Tree BG Biomass and BGB Carbon by Land Cover

Land Cover	BGB (million tonnes)				BGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	134.14	4.81	127.68	140.60	63.05	4.81	60.01	66.08
Non-Forest	3.08	24.82	2.32	3.85	1.45	24.82	1.09	1.81

(ii) Tree BG Biomass and BGB Carbon per ha by Land Cover

Land Cover	BGB (tonnes ha^{-1})				BGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	50.12	4.44	47.89	52.34	23.55	4.44	22.51	24.60
Non-Forest	2.65	24.75	1.99	3.30	1.25	24.75	0.94	1.55

(iii) Tree BG Biomass and Carbon per ha by Species

Species	BGB (tonnes ha^{-1})				BGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bombax ceiba	0.05	77.51	0.01	0.08	0.02	77.51	0.00	0.04
Phoebe goalparensis	0.05	71.65	0.01	0.09	0.02	71.65	0.01	0.04
Larix griffithii	0.05	61.74	0.02	0.09	0.03	61.74	0.01	0.04
Ailanthus integrifolia	0.06	68.93	0.02	0.09	0.03	68.93	0.01	0.04
Juglans regia	0.08	52.37	0.04	0.11	0.04	52.37	0.02	0.05
Sterculia villosa	0.10	46.62	0.06	0.15	0.05	46.62	0.03	0.07
Aphanamixis polystachya	0.11	42.73	0.06	0.16	0.05	42.73	0.03	0.07
Terminalia myriocarpa	0.12	55.48	0.06	0.19	0.06	55.48	0.03	0.09
Duabanga grandiflora	0.13	40.13	0.08	0.18	0.06	40.13	0.04	0.08
Cupressus spp.	0.13	163.35	(0.08)	0.34	0.06	163.35	(0.04)	0.16
Taxus baccata	0.18	41.17	0.11	0.25	0.08	41.17	0.05	0.12
Tetrameles nudiflora	0.18	58.81	0.07	0.29	0.09	58.81	0.04	0.14
Exbucklandia populnea	0.28	53.99	0.13	0.43	0.13	53.99	0.06	0.20
Engelhardtia spicata	0.51	23.49	0.39	0.63	0.24	23.49	0.18	0.30
Alnus spp.	0.59	24.54	0.44	0.73	0.28	24.54	0.21	0.34

Beilschmiedia spp.	0.60	24.17	0.46	0.75	0.28	24.17	0.21	0.35
Magnolia spp.	0.61	25.57	0.45	0.76	0.29	25.57	0.21	0.36
Juniperus spp.	0.66	31.89	0.45	0.88	0.31	31.89	0.21	0.41
Schima wallichii	0.68	21.73	0.53	0.83	0.32	21.73	0.25	0.39
Picea spinulosa	0.77	34.35	0.51	1.04	0.36	34.35	0.24	0.49
Pinus roxburghii	0.84	30.04	0.59	1.09	0.39	30.04	0.28	0.51
Betula spp.	1.08	15.79	0.91	1.25	0.51	15.79	0.43	0.59
Pinus wallichiana	1.28	26.61	0.94	1.62	0.60	26.61	0.44	0.76
Acer spp.	1.49	12.45	1.31	1.68	0.70	12.45	0.61	0.79
Symplocos spp.	1.63	90.65	0.15	3.10	0.76	90.65	0.07	1.46
Tsuga dumosa	1.95	23.61	1.49	2.41	0.92	23.61	0.70	1.13
Rhododendron spp.	2.50	12.03	2.20	2.80	1.17	12.03	1.03	1.31
Persea spp.	2.53	14.27	2.17	2.89	1.19	14.27	1.02	1.36
Castanopsis spp.	2.54	15.78	2.14	2.94	1.19	15.78	1.00	1.38
Abies densa	7.05	14.42	6.03	8.06	3.31	14.42	2.83	3.79
Quercus spp.	8.63	11.00	7.68	9.57	4.05	11.00	3.61	4.50
Others	16.77	5.53	15.84	17.70	7.88	5.53	7.45	8.32

(iv) Total estimates for tree BGB and BGB Carbon by DBH class

DBH Class	BGB (million tonnes)				BGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
10-20	14.29	6.14	13.42	15.17	6.72	6.14	6.31	7.13
20-30	15.04	4.21	14.40	15.67	7.07	4.21	6.77	7.36
30-40	15.79	4.01	15.16	16.42	7.42	4.01	7.12	7.72
40-50	15.65	4.50	14.95	16.35	7.36	4.50	7.02	7.69
50-60	15.55	5.45	14.71	16.40	7.31	5.45	6.91	7.71
60-70	14.71	6.16	13.81	15.62	6.92	6.16	6.49	7.34
70-80	13.28	7.22	12.32	14.24	6.24	7.22	5.79	6.69
80-90	12.97	8.74	11.84	14.10	6.10	8.74	5.56	6.63
90-100	9.71	10.27	8.71	10.71	4.56	10.27	4.10	5.03
100-110	6.28	13.76	5.42	7.14	2.95	13.76	2.55	3.36
110-120	6.08	15.12	5.16	7.00	2.86	15.12	2.42	3.29
120-130	4.34	18.96	3.52	5.17	2.04	18.96	1.65	2.43
130-140	4.71	84.15	0.75	8.67	2.21	84.15	0.35	4.08
140-150	2.32	26.49	1.70	2.93	1.09	26.49	0.80	1.38
150-160	1.75	34.74	1.14	2.36	0.82	34.74	0.54	1.11
160-170	0.82	56.79	0.36	1.29	0.39	56.79	0.17	0.61
170-180	0.73	56.13	0.32	1.14	0.34	56.13	0.15	0.54
180-190	0.56	64.76	0.20	0.93	0.26	64.76	0.09	0.44
>=190	1.48	56.16	0.65	2.31	0.70	56.16	0.31	1.09

(iv) Total estimates for BGB and BGB Carbon by Height class (million tonnes)

Height Class (m)	BGB (million tonnes)				BGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
<5	1.43	15.58	1.21	1.65	0.67	15.58	0.57	0.78
5-10	15.36	6.42	14.38	16.35	7.22	6.42	6.76	7.68
10-15	29.37	14.02	25.26	33.49	13.81	14.02	11.87	15.74
15-20	31.75	5.35	30.05	33.45	14.92	5.35	14.13	15.72
20-25	30.71	6.59	28.69	32.73	14.43	6.59	13.48	15.38
25-30	21.70	8.40	19.88	23.52	10.20	8.40	9.34	11.06
30-35	11.21	11.99	9.87	12.55	5.27	11.99	4.64	5.90
35-40	5.40	16.80	4.49	6.31	2.54	16.80	2.11	2.97
>= 40	4.00	26.08	2.96	5.04	1.88	26.08	1.39	2.37

4.2 Sapling BGB

(i) Total estimate for BGB and BGB Carbon by Land Cover

Land Cover	BGB (million tonnes)				BGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	9.21	41.51	5.39	13.03	4.33	41.51	2.53	6.12
Non-Forest	1.07	57.35	0.46	1.69	0.50	57.35	0.21	0.79

(ii) Estimate for BGB and BGB Carbon per ha by Land Cover

Land Cover	BGB (tonnes ha^{-1})				BGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	3.44	41.47	2.01	4.87	1.62	41.47	0.95	2.29
Non-Forest	0.92	57.32	0.39	1.45	0.43	57.32	0.18	0.68

(iii) Sapling BGB and BGB Carbon estimates per ha by Species

Species	BGB (tonnes ha^{-1})				BGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Abies densa	0.02	34.55	0.02	0.03	0.01	34.55	0.01	0.01
Acer spp.	0.08	155.97	(0.04)	0.21	0.04	155.97	(0.02)	0.10
Ailanthus integrifolia	0.00	91.74	0.00	0.00	0.00	91.74	0.00	0.00
Alnus spp.	0.01	72.62	0.00	0.01	0.00	72.62	0.00	0.01
Aphanamixis polystachya	0.00	43.25	0.00	0.01	0.00	43.25	0.00	0.00
Beilschmiedia spp.	0.01	30.01	0.00	0.01	0.00	30.01	0.00	0.00
Betula spp.	0.02	46.66	0.01	0.03	0.01	46.66	0.00	0.01
Bombax ceiba	0.00	160.28	(0.00)	0.00	0.00	160.28	(0.00)	0.00
Castanopsis spp.	0.04	23.84	0.03	0.05	0.02	23.84	0.01	0.02

Cupressus spp.	0.00	141.73	(0.00)	0.00	0.00	141.73	(0.00)	0.00
Duabanga grandiflora	0.00	121.31	(0.00)	0.00	0.00	121.31	(0.00)	0.00
Engelhardtia spicata	0.01	32.76	0.01	0.01	0.00	32.76	0.00	0.01
Exbucklandia populnea	0.00	55.39	0.00	0.00	0.00	55.39	0.00	0.00
Juglans regia	0.00	77.02	0.00	0.00	0.00	77.02	0.00	0.00
Juniperus spp.	0.01	46.48	0.00	0.01	0.00	46.48	0.00	0.01
Larix griffithii	0.00	122.02	(0.00)	0.00	0.00	122.02	(0.00)	0.00
Magnolia spp.	0.00	45.77	0.00	0.00	0.00	45.77	0.00	0.00
Persea spp.	0.03	18.56	0.03	0.04	0.02	18.56	0.01	0.02
Phoebe goalparensis	0.00	74.38	0.00	0.00	0.00	74.38	0.00	0.00
Picea spinulosa	0.00	46.20	0.00	0.00	0.00	46.20	0.00	0.00
Pinus roxburghii	0.01	46.62	0.01	0.02	0.01	46.62	0.00	0.01
Pinus wallichiana	0.02	42.92	0.01	0.03	0.01	42.92	0.01	0.02
Quercus spp.	0.07	19.97	0.06	0.09	0.03	19.97	0.03	0.04
Rhododendron spp.	0.33	60.37	0.13	0.54	0.16	60.37	0.06	0.25
Schima wallichii	0.01	33.45	0.01	0.02	0.01	33.45	0.00	0.01
Sterculia villosa	0.00	58.73	0.00	0.00	0.00	58.73	0.00	0.00
Symplocos spp.	0.10	14.98	0.09	0.12	0.05	14.98	0.04	0.05
Taxus baccata	0.00	145.52	(0.00)	0.00	0.00	145.52	(0.00)	0.00
Terminalia myriocarpa	0.00	76.26	0.00	0.00	0.00	76.26	0.00	0.00
Tetrameles nudiflora	0.00	161.30	(0.00)	0.00	0.00	161.30	(0.00)	0.00
Tsuga dumosa	0.00	55.80	0.00	0.01	0.00	55.80	0.00	0.00
Others	0.59	6.63	0.55	0.62	0.28	6.63	0.26	0.29

5. Coarse Woody Debris (CWD)

(i) Total estimates for CWD Biomass and Carbon in million tonnes

Land Class	CWD Biomass (million tonnes)				CWD Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	17.99	11.88	15.86	20.13	8.46	11.88	7.45	9.46
Non-Forest	0.31	112.76	(0.04)	0.66	0.15	112.76	(0.02)	0.31

(ii) CWD Biomass and Carbon per ha by Land Cover

Land Class	CWD Biomass (tonnes ha^{-1})				CWD Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	6.72	11.73	5.93	7.51	3.16	11.73	2.79	3.53
Non-Forest	0.27	112.74	(0.03)	0.57	0.12	112.74	(0.02)	0.27

6. Litter

(i) Total estimates for Litter Biomass and Carbon in million tonnes

Land Cover	Litter Biomass (million tonnes)				Litter Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	41.94	14.04	36.05	47.82	19.71	14.03	16.95	22.48
Non-Forest	18.07	38.18	11.17	24.97	8.50	38.17	5.25	11.74

(ii) Litter Biomass and Carbon per ha by Land Cover (tonnes ha-1)

Land Cover	Litter Biomass (tonnes ha^{-1})				Litter Biomass Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Forest	15.67	13.91	13.49	17.85	7.37	13.91	6.34	8.39
Non-Forest	15.54	38.14	9.61	21.47	7.31	38.13	4.52	10.09

7. Soil Organic Carbon (SOC)

(i) Per ha and total estimates for SOC by Land Cover

Land Cover	SOC Density (tonnes ha^{-1})				Total SOC (million tonnes)			
	Estimate	MoE (%)	Lower Limit	Upper Limit	Estimate	MoE (%)	Lower Limit	Upper Limit
Forest	68.12	7.44	63.05	73.19	182.33	7.67	168.35	196.31
Non-Forest	58.18	15.05	49.42	66.93	67.65	15.16	57.39	77.91

(ii) SOC Density (tonnes ha-1) in different soil layer by Land Cover

Soil Layer	Forest				Non-Forest			
	SOC	MoE (%)	Lower Limit	Upper Limit	SOC	MoE (%)	Lower Limit	Upper Limit
0-10 cm	28.71	7.32	26.61	30.81	26.84	15.83	22.59	31.09
10-20 cm	22.26	9.59	20.13	24.40	17.98	19.54	14.46	21.49
20-30 cm	17.15	9.70	15.48	18.81	13.36	18.40	10.90	15.82

(iii) Total estimates for SOC (million tonnes) in different soil layer by Land Cover

Soil Layer	Forest				Non-Forest			
	SOC	MoE (%)	Lower Limit	Upper Limit	SOC	MoE (%)	Lower Limit	Upper Limit
0-10 cm	76.84	7.55	71.04	82.64	31.21	15.94	26.24	36.19
10-20 cm	59.59	9.77	53.77	65.41	20.90	19.62	16.80	25.01
20-30 cm	45.90	9.88	41.36	50.43	15.54	18.49	12.66	18.41

Chapter 4: Forest Carbon by Different Category

4.1 Dzongkhag

1. Total Carbon estimate at Dzongkhag (million tonnes)

Dzongkhag	AGB	BGB	CWD	Litter	SOC	Total
Bumthang	14.40	3.80	1.05	2.11	12.85	34.20
Chhukha	12.24	3.33	0.23	2.36	9.08	27.24
Dagana	13.50	3.60	0.65	1.03	10.94	29.71
Gasa	5.55	1.42	0.14	0.60	4.98	12.69
Haa	13.17	3.45	0.48	0.97	13.44	31.52
Lhuentse	19.89	5.12	0.45	0.71	12.57	38.75
Mongar	17.06	4.48	0.34	0.77	11.49	34.14
Paro	6.92	1.80	0.27	0.79	6.29	16.06
Pemagatshel	5.27	1.46	0.08	0.62	3.42	10.85
Punakha	8.56	2.29	0.26	0.39	7.58	19.07
Samdrup Jongkhar	11.03	3.02	0.32	0.77	5.74	20.88
Samtse	6.26	1.73	0.12	0.47	5.88	14.48
Sarpang	11.62	3.12	0.49	0.87	8.93	25.02
Thimphu	7.79	2.03	0.14	0.46	5.70	16.12
Trashigang	16.11	4.21	0.53	1.09	11.59	33.54
Trashi Yangtse	9.02	2.35	0.29	0.76	7.60	20.02
Trongsa	16.39	4.24	0.67	1.92	11.25	34.48
Tsirang	3.67	1.01	0.09	0.26	2.14	7.17
Wangdue Phodrang	25.19	6.67	1.17	1.21	19.62	53.86
Zhemgang	25.27	6.19	0.74	1.37	10.83	44.40

2. Per ha carbon estimate by Dzongkhag (tonnes ha^{-1})

Dzongkhag	AGB	BGB	CWD	Litter	SOC	Total
Bumthang	101.41	26.74	7.37	14.84	90.45	240.81
Chhukha	75.12	20.45	1.41	14.52	55.76	167.26
Dagana	88.02	23.44	4.22	6.70	71.34	193.72
Gasa	84.72	21.76	2.19	9.14	76.05	193.86
Haa	106.59	27.95	3.90	7.85	108.81	255.11
Lhuentse	110.82	28.54	2.49	3.98	70.04	215.87
Mongar	99.55	26.16	1.96	4.48	67.08	199.24
Paro	92.59	24.04	3.59	10.60	84.14	214.96
Pemagatshel	59.36	16.48	0.90	6.99	38.58	122.30
Punakha	96.45	25.81	2.89	4.45	85.45	215.05
Samdrup Jongkhar	64.07	17.54	1.87	4.48	33.35	121.30
Samtse	62.77	17.37	1.25	4.73	58.97	145.09

Sarpang	80.19	21.50	3.38	5.97	61.62	172.65
Thimphu	95.48	24.92	1.67	5.67	69.84	197.57
Trashigang	98.93	25.85	3.25	6.68	71.18	205.89
Trashi Yangtse	110.19	28.77	3.52	9.26	92.91	244.65
Trongsa	111.69	28.92	4.60	13.06	76.65	234.91
Tsirang	67.57	18.58	1.61	4.73	39.35	131.84
Wangdue Phodrang	97.26	25.75	4.50	4.67	75.78	207.96
Zhemgang	113.26	27.76	3.31	6.16	48.56	199.05

4. AGB in Dzongkhag

(i) Tree Biomass and Carbon per ha estimate by Dzongkhag

Dzongkhag	AG Biomass (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	212.4	12.7	185.3	239.4	99.8	12.7	87.1	112.5
Chhukha	155.7	15.1	132.2	179.2	73.2	15.1	62.1	84.2
Dagana	182.7	12.6	159.6	205.8	85.9	12.6	75.0	96.7
Gasa	132.6	27.7	95.8	169.3	62.3	27.7	45.0	79.6
Haa	222.7	16.7	185.6	259.9	104.7	16.7	87.2	122.2
Lhuentse	232.9	18.9	188.9	276.8	109.4	18.9	88.8	130.1
Mongar	207.5	13.2	180.1	234.8	97.5	13.2	84.7	110.3
Paro	189.3	21.8	148.1	230.5	89.0	21.8	69.6	108.3
Pemagatshel	118.3	16.3	99.1	137.5	55.6	16.3	46.6	64.6
Punakha	201.1	13.0	174.9	227.3	94.5	13.0	82.2	106.8
Samdrup Jongkhar	131.0	14.4	112.1	149.9	61.6	14.4	52.7	70.4
Samtse	131.1	17.4	108.3	154.0	61.6	17.4	50.9	72.4
Sarpang	166.1	14.0	142.8	189.4	78.1	14.0	67.1	89.0
Thimphu	201.0	20.9	158.9	243.1	94.5	20.9	74.7	114.2
Trashigang	205.4	15.8	173.0	237.8	96.5	15.8	81.3	111.8
Trashi Yangtse	231.2	18.8	187.8	274.6	108.7	18.8	88.3	129.1
Trongsa	232.9	17.1	193.1	272.7	109.5	17.1	90.8	128.1
Tsirang	137.4	20.3	109.6	165.3	64.6	20.3	51.5	77.7
Wangdue Phodrang	203.1	11.7	179.4	226.9	95.5	11.7	84.3	106.6
Zhemgang	236.8	47.5	124.3	349.3	111.3	47.5	58.4	164.2

(ii) Total Biomass and Carbon estimate for tree (AGB) by Dzongkhag

Dzongkhag	AG Biomass (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	30.16	14.90	25.67	34.66	14.18	14.90	12.06	16.29
Chhukha	25.36	16.04	21.29	29.42	11.92	16.04	10.01	13.83
Dagana	28.02	13.84	24.14	31.90	13.17	13.84	11.35	14.99

Gasa	8.68	28.33	6.22	11.14	4.08	28.33	2.92	5.23
Haa	27.52	18.83	22.34	32.70	12.93	18.83	10.50	15.37
Lhuentse	41.80	20.20	33.36	50.24	19.65	20.20	15.68	23.61
Mongar	35.54	14.25	30.48	40.61	16.71	14.25	14.32	19.09
Paro	14.14	24.36	10.70	17.59	6.65	24.36	5.03	8.27
Pemagatshel	10.49	18.08	8.60	12.39	4.93	18.08	4.04	5.82
Punakha	17.84	16.16	14.95	20.72	8.38	16.16	7.03	9.74
Samdrup Jongkhar	22.54	15.31	19.09	26.00	10.60	15.31	8.97	12.22
Samtse	13.08	19.67	10.51	15.66	6.15	19.67	4.94	7.36
Sarpang	24.07	15.42	20.36	27.78	11.31	15.42	9.57	13.06
Thimphu	16.40	22.91	12.64	20.15	7.71	22.91	5.94	9.47
Trashigang	33.45	17.41	27.63	39.28	15.72	17.41	12.99	18.46
Trashi Yangtse	18.92	21.48	14.86	22.98	8.89	21.48	6.98	10.80
Trongsa	34.18	18.54	27.85	40.52	16.07	18.54	13.09	19.04
Tsirang	7.47	23.51	5.72	9.23	3.51	23.51	2.69	4.34
Wangdue Phodrang	52.60	13.14	45.69	59.52	24.72	13.14	21.47	27.97
Zhemgang	52.82	47.65	27.65	78.00	24.83	47.65	13.00	36.66

(iii) Sapling BGB Biomass and Carbon per ha by Dzongkhag

Dzongkhag	AG Biomass (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	1.81	22.26	1.41	2.21	0.85	22.26	0.66	1.04
Chhukha	3.20	17.56	2.64	3.77	1.51	17.56	1.24	1.77
Dagana	2.26	19.14	1.83	2.70	1.06	19.14	0.86	1.27
Gasa	41.99	175.68	(31.78)	115.75	19.73	175.68	(14.94)	54.40
Haa	3.09	26.08	2.29	3.90	1.45	26.08	1.07	1.83
Lhuentse	2.03	22.29	1.58	2.49	0.96	22.29	0.74	1.17
Mongar	2.19	23.21	1.68	2.70	1.03	23.21	0.79	1.27
Paro	3.28	29.71	2.31	4.25	1.54	29.71	1.08	2.00
Pemagatshel	4.48	32.96	3.00	5.96	2.11	32.96	1.41	2.80
Punakha	2.44	37.52	1.52	3.36	1.15	37.52	0.72	1.58
Samdrup Jongkhar	2.94	16.63	2.45	3.43	1.38	16.63	1.15	1.61
Samtse	1.48	19.78	1.19	1.77	0.70	19.78	0.56	0.83
Sarpang	2.43	12.88	2.12	2.74	1.14	12.88	0.99	1.29
Thimphu	0.38	34.45	0.25	0.51	0.18	34.45	0.12	0.24
Trashigang	3.34	18.05	2.74	3.94	1.57	18.05	1.29	1.85
Trashi Yangtse	2.73	28.96	1.94	3.52	1.28	28.96	0.91	1.65
Trongsa	3.43	24.63	2.58	4.27	1.61	24.63	1.21	2.01
Tsirang	3.34	28.67	2.38	4.29	1.57	28.67	1.12	2.02
Wangdue Phodrang	3.06	22.85	2.36	3.75	1.44	22.85	1.11	1.76
Zhemgang	2.80	12.88	2.44	3.16	1.32	12.88	1.15	1.48

(iv) Total estimates for Sapling Biomass and Carbon estimate by Dzongkhag

Dzongkhag	AG Biomass (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	0.26	23.56	0.20	0.32	0.12	23.56	0.09	0.15
Chhukha	0.52	18.37	0.43	0.62	0.25	18.37	0.20	0.29
Dagana	0.35	19.96	0.28	0.42	0.16	19.96	0.13	0.20
Gasa	2.75	175.78	(2.08)	7.58	1.29	175.78	(0.98)	3.56
Haa	0.38	27.49	0.28	0.49	0.18	27.49	0.13	0.23
Lhuentse	0.37	23.42	0.28	0.45	0.17	23.42	0.13	0.21
Mongar	0.38	23.84	0.29	0.47	0.18	23.84	0.13	0.22
Paro	0.25	31.67	0.17	0.32	0.12	31.67	0.08	0.15
Pemagatshel	0.40	33.90	0.26	0.53	0.19	33.90	0.12	0.25
Punakha	0.22	38.72	0.13	0.30	0.10	38.72	0.06	0.14
Samdrup Jongkhar	0.51	17.41	0.42	0.59	0.24	17.41	0.20	0.28
Samtse	0.15	21.80	0.12	0.18	0.07	21.80	0.05	0.08
Sarpang	0.35	14.38	0.30	0.40	0.17	14.38	0.14	0.19
Thimphu	0.03	35.69	0.02	0.04	0.01	35.69	0.01	0.02
Trashigang	0.54	19.50	0.44	0.65	0.26	19.50	0.21	0.31
Trashi Yangtse	0.22	30.78	0.15	0.29	0.10	30.78	0.07	0.14
Trongsa	0.50	25.66	0.37	0.63	0.24	25.66	0.18	0.30
Tsirang	0.18	31.05	0.13	0.24	0.09	31.05	0.06	0.11
Wangdue Phodrang	0.79	23.63	0.60	0.98	0.37	23.63	0.28	0.46
Zhemgang	0.62	13.46	0.54	0.71	0.29	13.46	0.25	0.33

(v) Shrub AG Biomass and Carbon per ha by Dzongkhag

Dzongkhag	AG Biomass (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	1.11	96.55	0.04	2.19	0.52	96.55	0.02	1.03
Chhukha	0.58	51.80	0.28	0.89	0.27	51.80	0.13	0.42
Dagana	2.02	83.84	0.33	3.72	0.95	83.84	0.15	1.75
Gasa	5.46	177.84	(4.25)	15.17	2.57	177.84	(2.00)	7.13
Haa	0.47	37.64	0.29	0.65	0.22	37.64	0.14	0.30
Lhuentse	0.66	78.12	0.15	1.18	0.31	78.12	0.07	0.56
Mongar	1.63	77.29	0.37	2.89	0.77	77.29	0.17	1.36
Paro	3.93	61.79	1.50	6.36	1.85	61.79	0.71	2.99
Pemagatshel	3.21	60.43	1.27	5.16	1.51	60.43	0.60	2.42
Punakha	1.53	143.70	(0.67)	3.74	0.72	143.70	(0.31)	1.76
Samdrup Jongkhar	1.88	50.30	0.93	2.82	0.88	50.30	0.44	1.32
Samtse	0.89	41.86	0.52	1.26	0.42	41.86	0.24	0.59
Sarpang	1.83	62.30	0.69	2.97	0.86	62.30	0.32	1.39

Thimphu	1.63	72.72	0.44	2.82	0.77	72.72	0.21	1.32
Trashigang	1.28	69.35	0.39	2.17	0.60	69.35	0.18	1.02
Trashi Yangtse	0.28	54.83	0.13	0.43	0.13	54.83	0.06	0.20
Trongsa	1.02	53.87	0.47	1.57	0.48	53.87	0.22	0.74
Tsirang	1.45	64.05	0.52	2.38	0.68	64.05	0.25	1.12
Wangdue Phodrang	0.40	31.04	0.27	0.52	0.19	31.04	0.13	0.24
Zhemgang	0.69	64.67	0.24	1.13	0.32	64.67	0.11	0.53

(vi) Total estimate for Shrub biomass and carbon by Dzongkhag

Dzongkhag	AG Biomass (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	0.16	96.86	0.00	0.31	0.07	96.86	0.00	0.15
Chhukha	0.10	52.07	0.05	0.14	0.04	52.07	0.02	0.07
Dagana	0.31	84.03	0.05	0.57	0.15	84.03	0.02	0.27
Gasa	0.36	177.93	(0.28)	0.99	0.17	177.93	(0.13)	0.47
Haa	0.06	38.63	0.04	0.08	0.03	38.63	0.02	0.04
Lhuentse	0.12	78.45	0.03	0.21	0.06	78.45	0.01	0.10
Mongar	0.28	77.48	0.06	0.50	0.13	77.48	0.03	0.23
Paro	0.29	62.75	0.11	0.48	0.14	62.75	0.05	0.22
Pemagatshel	0.29	60.95	0.11	0.46	0.13	60.95	0.05	0.22
Punakha	0.14	144.02	(0.06)	0.33	0.06	144.02	(0.03)	0.16
Samdrup Jongkhar	0.32	50.56	0.16	0.49	0.15	50.56	0.07	0.23
Samtse	0.09	42.85	0.05	0.13	0.04	42.85	0.02	0.06
Sarpang	0.26	62.62	0.10	0.43	0.12	62.62	0.05	0.20
Thimphu	0.13	73.32	0.04	0.23	0.06	73.32	0.02	0.11
Trashigang	0.21	69.74	0.06	0.35	0.10	69.74	0.03	0.17
Trashi Yangtse	0.02	55.82	0.01	0.04	0.01	55.82	0.00	0.02
Trongsa	0.15	54.35	0.07	0.23	0.07	54.35	0.03	0.11
Tsirang	0.08	65.15	0.03	0.13	0.04	65.15	0.01	0.06
Wangdue Phodrang	0.10	31.62	0.07	0.13	0.05	31.62	0.03	0.06
Zhemgang	0.15	64.78	0.05	0.25	0.07	64.78	0.03	0.12

(vii) Herb AG Biomass and Carbon per ha estimate by Dzongkhag

Dzongkhag	AG Biomass (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	0.46	96.82	0.01	0.90	0.22	96.82	0.01	0.42
Chhukha	0.36	46.07	0.19	0.52	0.17	46.07	0.09	0.25
Dagana	0.31	47.89	0.16	0.45	0.14	47.89	0.08	0.21
Gasa	0.26	108.00	(0.02)	0.53	0.12	108.00	(0.01)	0.25
Haa	0.49	69.40	0.15	0.83	0.23	69.40	0.07	0.39

Lhuentse	0.23	108.46	(0.02)	0.49	0.11	108.46	(0.01)	0.23
Mongar	0.53	81.55	0.10	0.96	0.25	81.55	0.05	0.45
Paro	0.48	114.14	(0.07)	1.03	0.23	114.14	(0.03)	0.48
Pemagatshel	0.29	77.11	0.07	0.51	0.14	77.11	0.03	0.24
Punakha	0.14	109.71	(0.01)	0.29	0.07	109.71	(0.01)	0.14
Samdrup Jongkhar	0.53	54.84	0.24	0.82	0.25	54.84	0.11	0.38
Samtse	0.06	25.34	0.04	0.07	0.03	25.34	0.02	0.03
Sarpang	0.27	49.56	0.13	0.40	0.13	49.56	0.06	0.19
Thimphu	0.14	94.73	0.01	0.28	0.07	94.73	0.00	0.13
Trashigang	0.47	35.69	0.30	0.64	0.22	35.69	0.14	0.30
Trashi Yangtse	0.25	34.36	0.16	0.33	0.12	34.36	0.08	0.16
Trongsa	0.30	52.76	0.14	0.46	0.14	52.76	0.07	0.22
Tsirang	1.55	143.59	(0.68)	3.78	0.73	143.59	(0.32)	1.78
Wangdue Phodrang	0.36	56.25	0.16	0.56	0.17	56.25	0.07	0.26
Zhemgang	0.70	62.30	0.26	1.13	0.33	62.30	0.12	0.53

(viii) Total estimate for Herb biomass and carbon by Dzongkhag

Dzongkhag	AG Biomass (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	0.07	97.13	0.00	0.13	0.03	97.13	0.00	0.06
Chhukha	0.06	46.39	0.03	0.09	0.03	46.39	0.01	0.04
Dagana	0.05	48.23	0.02	0.07	0.02	48.23	0.01	0.03
Gasa	0.02	108.15	(0.00)	0.03	0.01	108.15	(0.00)	0.02
Haa	0.06	69.95	0.02	0.10	0.03	69.95	0.01	0.05
Lhuentse	0.04	108.70	(0.00)	0.09	0.02	108.70	(0.00)	0.04
Mongar	0.09	81.73	0.02	0.17	0.04	81.73	0.01	0.08
Paro	0.04	114.67	(0.01)	0.08	0.02	114.67	(0.00)	0.04
Pemagatshel	0.03	77.52	0.01	0.05	0.01	77.52	0.00	0.02
Punakha	0.01	110.13	(0.00)	0.03	0.01	110.13	(0.00)	0.01
Samdrup Jongkhar	0.09	55.08	0.04	0.14	0.04	55.08	0.02	0.07
Samtse	0.01	26.94	0.00	0.01	0.00	26.94	0.00	0.00
Sarpang	0.04	49.97	0.02	0.06	0.02	49.97	0.01	0.03
Thimphu	0.01	95.19	0.00	0.02	0.01	95.19	0.00	0.01
Trashigang	0.08	36.45	0.05	0.11	0.04	36.45	0.02	0.05
Trashi Yangtse	0.02	35.90	0.01	0.03	0.01	35.90	0.01	0.01
Trongsa	0.04	53.25	0.02	0.07	0.02	53.25	0.01	0.03
Tsirang	0.08	144.09	(0.04)	0.21	0.04	144.09	(0.02)	0.10
Wangdue Phodrang	0.09	56.57	0.04	0.14	0.04	56.57	0.02	0.07
Zhemgang	0.16	62.42	0.06	0.25	0.07	62.42	0.03	0.12

5. BGB in Dzongkhag

(i) Tree Biomass and Carbon estimate by Dzongkhag

Dzongkhag	BG Biomass (tonnes ha^{-1})				BGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	56.13	11.65	49.59	62.67	26.38	11.65	23.31	29.46
Chhukha	42.20	13.57	36.47	47.93	19.83	13.57	17.14	22.53
Dagana	48.91	11.47	43.30	54.52	22.99	11.47	20.35	25.62
Gasa	36.40	25.17	27.24	45.56	17.11	25.17	12.80	21.41
Haa	58.21	15.17	49.38	67.04	27.36	15.17	23.21	31.51
Lhuentse	59.86	17.03	49.66	70.05	28.13	17.03	23.34	32.92
Mongar	54.74	12.03	48.15	61.33	25.73	12.03	22.63	28.82
Paro	49.85	20.02	39.87	59.83	23.43	20.02	18.74	28.12
Pemagatshel	33.31	14.66	28.43	38.19	15.66	14.66	13.36	17.95
Punakha	53.91	11.74	47.58	60.24	25.34	11.74	22.36	28.31
Samdrup Jongkhar	36.08	13.07	31.36	40.79	16.96	13.07	14.74	19.17
Samtse	36.30	15.63	30.63	41.98	17.06	15.63	14.39	19.73
Sarpang	44.70	12.64	39.05	50.35	21.01	12.64	18.35	23.66
Thimphu	52.82	19.07	42.75	62.90	24.83	19.07	20.09	29.56
Trashigang	53.66	14.27	46.00	61.31	25.22	14.27	21.62	28.82
Trashi Yangtse	60.09	16.98	49.88	70.29	28.24	16.98	23.44	33.04
Trongsa	60.15	15.46	50.85	69.45	28.27	15.46	23.90	32.64
Tsirang	38.15	18.20	31.21	45.10	17.93	18.20	14.67	21.20
Wangdue Phodrang	53.57	10.53	47.92	59.21	25.18	10.53	22.52	27.83
Zhemgang	57.88	32.40	39.13	76.64	27.20	32.40	18.39	36.02

(ii) Total estimates of tree BGB carbon by Dzongkhag

Dzongkhag	AG Biomass (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	7.97	13.98	6.86	9.09	3.75	13.98	3.22	4.27
Chhukha	6.87	14.60	5.87	7.88	3.23	14.60	2.76	3.70
Dagana	7.50	12.80	6.54	8.46	3.53	12.80	3.07	3.98
Gasa	2.38	25.80	1.77	3.00	1.12	25.80	0.83	1.41
Haa	7.19	17.49	5.93	8.45	3.38	17.49	2.79	3.97
Lhuentse	10.74	18.49	8.76	12.73	5.05	18.49	4.12	5.98
Mongar	9.38	13.21	8.14	10.62	4.41	13.21	3.83	4.99
Paro	3.72	22.83	2.87	4.57	1.75	22.83	1.35	2.15
Pemagatshel	2.95	16.66	2.46	3.45	1.39	16.66	1.16	1.62
Punakha	4.78	15.14	4.06	5.51	2.25	15.14	1.91	2.59
Samdrup Jongkhar	6.21	14.05	5.34	7.08	2.92	14.05	2.51	3.33
Samtse	3.62	18.11	2.97	4.28	1.70	18.11	1.39	2.01

Sarpang	6.48	14.16	5.56	7.40	3.04	14.16	2.61	3.48
Thimphu	4.31	21.22	3.39	5.22	2.03	21.22	1.60	2.45
Trashigang	8.74	16.07	7.33	10.14	4.11	16.07	3.45	4.77
Trashi Yangtse	4.92	19.93	3.94	5.90	2.31	19.93	1.85	2.77
Trongsa	8.83	17.07	7.32	10.33	4.15	17.07	3.44	4.86
Tsirang	2.07	21.76	1.62	2.53	0.98	21.76	0.76	1.19
Wangdue Phodrang	13.87	12.13	12.19	15.55	6.52	12.13	5.73	7.31
Zhemgang	12.91	32.64	8.70	17.13	6.07	32.64	4.09	8.05

(iii) Sapling BG Biomass and carbon by Dzongkhag

Dzongkhag	BG Biomass (tonnes ha^{-1})				BGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	0.77	20.50	0.61	0.93	0.36	20.50	0.29	0.44
Chhukha	1.32	15.66	1.11	1.52	0.62	15.66	0.52	0.72
Dagana	0.96	16.68	0.80	1.13	0.45	16.68	0.38	0.53
Gasa	9.90	161.72	(6.11)	25.91	4.65	161.72	(2.87)	12.18
Haa	1.26	23.01	0.97	1.55	0.59	23.01	0.46	0.73
Lhuentse	0.87	20.26	0.69	1.04	0.41	20.26	0.32	0.49
Mongar	0.92	20.96	0.72	1.11	0.43	20.96	0.34	0.52
Paro	1.31	26.96	0.96	1.66	0.62	26.96	0.45	0.78
Pemagatshel	1.75	28.07	1.26	2.25	0.82	28.07	0.59	1.06
Punakha	1.00	33.07	0.67	1.33	0.47	33.07	0.32	0.63
Samdrup Jongkhar	1.23	14.26	1.06	1.41	0.58	14.26	0.50	0.66
Samtse	0.66	18.18	0.54	0.78	0.31	18.18	0.25	0.37
Sarpang	1.04	11.74	0.92	1.16	0.49	11.74	0.43	0.55
Thimphu	0.19	31.46	0.13	0.25	0.09	31.46	0.06	0.12
Trashigang	1.34	16.45	1.12	1.57	0.63	16.45	0.53	0.74
Trashi Yangtse	1.13	25.84	0.83	1.42	0.53	25.84	0.39	0.67
Trongsa	1.38	21.84	1.08	1.69	0.65	21.84	0.51	0.79
Tsirang	1.37	25.55	1.02	1.72	0.64	25.55	0.48	0.81
Wangdue Phodrang	1.22	20.03	0.98	1.47	0.57	20.03	0.46	0.69
Zhemgang	1.18	11.43	1.05	1.32	0.55	11.43	0.49	0.62

(iv) Total estimates for BG biomass and carbon by Dzongkhag

Dzongkhag	BG Biomass (million tonnes)				BGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	0.11	21.91	0.09	0.13	0.05	21.91	0.04	0.06
Chhukha	0.21	16.56	0.18	0.25	0.10	16.56	0.08	0.12
Dagana	0.15	17.61	0.12	0.17	0.07	17.61	0.06	0.08
Gasa	0.65	161.82	(0.40)	1.70	0.30	161.82	(0.19)	0.80

Haa	0.16	24.60	0.12	0.19	0.07	24.60	0.06	0.09
Lhuentse	0.16	21.50	0.12	0.19	0.07	21.50	0.06	0.09
Mongar	0.16	21.65	0.12	0.19	0.07	21.65	0.06	0.09
Paro	0.10	29.10	0.07	0.13	0.05	29.10	0.03	0.06
Pemagatshel	0.16	29.16	0.11	0.20	0.07	29.16	0.05	0.09
Punakha	0.09	34.43	0.06	0.12	0.04	34.43	0.03	0.06
Samdrup Jongkhar	0.21	15.16	0.18	0.24	0.10	15.16	0.08	0.11
Samtse	0.07	20.36	0.05	0.08	0.03	20.36	0.02	0.04
Sarpang	0.15	13.36	0.13	0.17	0.07	13.36	0.06	0.08
Thimphu	0.02	32.82	0.01	0.02	0.01	32.82	0.00	0.01
Trashigang	0.22	18.04	0.18	0.26	0.10	18.04	0.08	0.12
Trashi Yangtse	0.09	27.86	0.07	0.12	0.04	27.86	0.03	0.06
Trongsa	0.20	23.00	0.16	0.25	0.10	23.00	0.07	0.12
Tsirang	0.07	28.20	0.05	0.10	0.04	28.20	0.03	0.04
Wangdue Phodrang	0.32	20.92	0.25	0.38	0.15	20.92	0.12	0.18
Zhemgang	0.26	12.08	0.23	0.30	0.12	12.08	0.11	

6. Coarse Woody Debris

(i) CWD Biomass and Carbon by Dzongkhag

Dzongkhag	CWD Biomass (tonnes ha^{-1})				CWD Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	15.68	36.21	10.00	21.36	7.37	36.21	4.70	10.04
Chhukha	3.00	112.47	(0.37)	6.36	1.41	112.47	(0.18)	2.99
Dagana	8.97	25.59	6.68	11.27	4.22	25.59	3.14	5.30
Gasa	4.66	78.33	1.01	8.31	2.19	78.33	0.47	3.91
Haa	8.30	64.35	2.96	13.64	3.90	64.35	1.39	6.41
Lhuentse	5.29	47.44	2.78	7.80	2.49	47.44	1.31	3.66
Mongar	4.18	59.03	1.71	6.64	1.96	59.03	0.80	3.12
Paro	7.65	48.08	3.97	11.32	3.59	48.08	1.87	5.32
Pemagatshel	1.91	73.30	0.51	3.30	0.90	73.30	0.24	1.55
Punakha	6.15	71.53	1.75	10.56	2.89	71.53	0.82	4.96
Samdrup Jongkhar	3.98	49.09	2.03	5.94	1.87	49.09	0.95	2.79
Samtse	2.66	91.51	0.23	5.09	1.25	91.51	0.11	2.39
Sarpang	7.19	50.42	3.56	10.81	3.38	50.42	1.67	5.08
Thimphu	3.56	75.39	0.88	6.25	1.67	75.39	0.41	2.94
Trashigang	6.92	37.77	4.31	9.53	3.25	37.77	2.02	4.48
Trashi Yangtse	7.48	54.19	3.43	11.54	3.52	54.19	1.61	5.42
Trongsa	9.78	44.45	5.43	14.12	4.60	44.45	2.55	6.64
Tsirang	3.43	112.52	(0.43)	7.29	1.61	112.52	(0.20)	3.43
Wangdue Phodrang	9.58	35.79	6.15	13.01	4.50	35.79	2.89	6.12
Zhemgang	7.04	31.06	4.86	9.23	3.31	31.06	2.28	

(ii) Total estimates for CWD biomass and Carbon by Dzongkhag

Dzongkhag	CWD Biomass (million tonnes)				CWD Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	2.23	37.02	1.40	3.05	1.05	37.02	0.66	1.43
Chhukha	0.49	112.60	(0.06)	1.04	0.23	112.60	(0.03)	0.49
Dagana	1.38	26.21	1.02	1.74	0.65	26.21	0.48	0.82
Gasa	0.31	78.54	0.07	0.54	0.14	78.54	0.03	0.26
Haa	1.03	64.94	0.36	1.69	0.48	64.94	0.17	0.80
Lhuentse	0.95	47.99	0.49	1.40	0.45	47.99	0.23	0.66
Mongar	0.72	59.28	0.29	1.14	0.34	59.28	0.14	0.54
Paro	0.57	49.31	0.29	0.85	0.27	49.31	0.14	0.40
Pemagatshel	0.17	73.73	0.04	0.29	0.08	73.73	0.02	0.14
Punakha	0.55	72.16	0.15	0.94	0.26	72.16	0.07	0.44
Samdrup Jongkhar	0.69	49.36	0.35	1.02	0.32	49.36	0.16	0.48
Samtse	0.27	91.97	0.02	0.51	0.12	91.97	0.01	0.24
Sarpang	1.04	50.82	0.51	1.57	0.49	50.82	0.24	0.74
Thimphu	0.29	75.96	0.07	0.51	0.14	75.96	0.03	0.24
Trashigang	1.13	38.48	0.69	1.56	0.53	38.48	0.33	0.73
Trashi Yangtse	0.61	55.19	0.27	0.95	0.29	55.19	0.13	0.45
Trongsa	1.44	45.04	0.79	2.08	0.67	45.04	0.37	0.98
Tsirang	0.19	113.15	(0.02)	0.40	0.09	113.15	(0.01)	0.19
Wangdue Phodrang	2.48	36.29	1.58	3.38	1.17	36.29	0.74	1.59
Zhemgang	1.57	31.30	1.08	2.06	0.74	31.30	0.51	0.97

7. Litter

(i) Litter Biomass and Carbon per ha by Dzongkhag

Dzongkhag	Litter Biomass (tonnes ha^{-1})				Litter Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	31.58	52.88	14.88	48.28	14.84	52.87	7.00	22.69
Chhukha	30.88	52.16	14.77	46.99	14.52	52.16	6.94	22.09
Dagana	14.26	51.21	6.96	21.57	6.70	51.21	3.27	10.14
Gasa	19.44	145.88	(8.92)	47.79	9.14	145.81	(4.19)	22.47
Haa	16.69	50.82	8.21	25.18	7.85	50.83	3.86	11.84
Lhuentse	8.47	63.44	3.10	13.84	3.98	63.42	1.46	6.51
Mongar	9.54	48.33	4.93	14.15	4.48	48.32	2.32	6.65
Paro	22.56	75.30	5.57	39.54	10.60	75.28	2.62	18.59
Pemagatshel	14.86	35.42	9.60	20.13	6.99	35.41	4.51	9.46
Punakha	9.47	130.22	(2.86)	21.81	4.45	130.24	(1.35)	10.25
Samdrup Jongkhar	9.53	36.51	6.05	13.01	4.48	36.50	2.84	6.12

Samtse	10.07	42.65	5.77	14.36	4.73	42.66	2.71	6.75
Sarpang	12.71	22.18	9.89	15.52	5.97	22.18	4.65	7.30
Thimphu	12.06	35.92	7.73	16.40	5.67	35.90	3.63	7.71
Trashigang	14.20	33.28	9.47	18.93	6.68	33.27	4.46	8.90
Trashi Yangtse	19.70	32.71	13.26	26.15	9.26	32.70	6.23	12.29
Trongsa	27.78	67.12	9.13	46.42	13.06	67.11	4.29	21.82
Tsirang	10.06	47.70	5.26	14.86	4.73	47.70	2.47	6.99
Wangdue Phodrang	9.94	33.05	6.65	13.22	4.67	33.03	3.13	6.22
Zhemgang	13.10	33.35	8.73	17.47	6.16	33.34	4.11	8.21

(ii) Total estimates for Litter Biomass and Carbon by Dzongkhag

Dzongkhag	Litter Biomass (million tonnes)				Litter Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	4.48	53.44	2.09	6.88	2.11	53.43	0.98	3.23
Chhukha	5.03	52.44	2.39	7.67	2.36	52.44	1.12	3.60
Dagana	2.19	51.53	1.06	3.31	1.03	51.52	0.50	1.56
Gasa	1.27	145.99	(0.59)	3.13	0.60	145.92	(0.27)	1.47
Haa	2.06	51.56	1.00	3.13	0.97	51.57	0.47	1.47
Lhuentse	1.52	63.84	0.55	2.49	0.71	63.82	0.26	1.17
Mongar	1.63	48.63	0.84	2.43	0.77	48.63	0.39	1.14
Paro	1.69	76.09	0.40	2.97	0.79	76.07	0.19	1.39
Pemagatshel	1.32	36.30	0.84	1.80	0.62	36.29	0.39	0.84
Punakha	0.84	130.58	(0.26)	1.94	0.39	130.59	(0.12)	0.91
Samdrup Jongkhar	1.64	36.87	1.04	2.25	0.77	36.87	0.49	1.06
Samtse	1.00	43.62	0.57	1.44	0.47	43.63	0.27	0.68
Sarpang	1.84	23.08	1.42	2.27	0.87	23.08	0.67	1.07
Thimphu	0.98	37.11	0.62	1.35	0.46	37.09	0.29	0.63
Trashigang	2.31	34.09	1.52	3.10	1.09	34.08	0.72	1.46
Trashi Yangtse	1.61	34.33	1.06	2.17	0.76	34.32	0.50	1.02
Trongsa	4.08	67.51	1.32	6.83	1.92	67.49	0.62	3.21
Tsirang	0.55	49.17	0.28	0.82	0.26	49.17	0.13	0.38
Wangdue Phodrang	2.57	33.59	1.71	3.44	1.21	33.57	0.80	1.62
Zhemgang	2.92	33.58	1.94	3.90	1.37	33.56	0.91	1.83

8. SOC in different layers

(i) Total estimates of SOC in different Layer (million tonnes)

Dzongkhag	0-10 cm		10-20 cm		20-30 cm	
	SOC	MoE (%)	SOC	MoE (%)	SOC	MoE (%)
Bumthang	5.15	19.28	4.52	48.63	3.18	30.62
Chhukha	4.23	28.49	2.80	26.42	2.05	28.04

Dagana	4.60	27.11	3.66	35.05	2.68	44.83
Gasa	2.32	61.19	1.62	42.60	1.03	73.71
Haa	6.75	52.11	4.77	55.91	1.93	22.04
Lhuentse	5.32	27.41	4.04	31.26	3.21	45.00
Mongar	4.50	18.17	3.84	28.76	3.16	32.64
Paro	2.95	31.48	1.99	41.94	1.34	47.44
Pemagatshel	1.35	37.09	1.12	58.37	0.95	61.49
Punakha	3.64	26.21	2.12	36.26	1.81	45.10
Samdrup Jongkhar	2.60	31.52	1.73	37.87	1.41	35.86
Samtse	2.45	30.36	1.83	33.01	1.61	36.63
Sarpang	4.20	22.09	2.71	31.77	2.02	46.31
Thimphu	2.53	26.35	1.75	48.29	1.41	45.96
Trashigang	4.38	27.76	3.96	30.02	3.26	34.05
Trashi Yangtse	2.53	24.18	2.76	24.25	2.31	26.57
Trongsa	4.08	35.63	3.99	54.64	3.18	56.26
Tsirang	1.03	42.86	0.49	63.96	0.63	57.52
Wangdue Phodrang	7.83	18.23	6.53	25.87	5.27	31.70
Zhemgang	4.71	32.76	3.21	42.38	2.91	52.56
Grand Total	77.17	620.28	59.43	797.27	45.34	854.32

(ii) SOC estimates in different SOC layer (tonnes ha-[1])

Dzongkhag	0-10 cm		10-20 cm		20-30 cm	
	SOC	MoE (%)	SOC	MoE (%)	SOC	MoE (%)
Bumthang	36.25	17.67	31.80	48.02	22.40	29.63
Chhukha	25.98	27.98	17.22	25.87	12.56	27.52
Dagana	30.02	26.51	23.84	34.59	17.49	44.47
Gasa	35.50	60.93	24.77	42.22	15.77	73.49
Haa	54.63	51.38	38.58	55.23	15.60	20.24
Lhuentse	29.66	26.45	22.48	30.42	17.90	44.42
Mongar	26.25	17.34	22.40	28.24	18.43	32.19
Paro	39.54	29.51	26.62	40.49	17.97	46.15
Pemagatshel	15.21	36.23	12.63	57.83	10.74	60.97
Punakha	41.08	24.41	23.91	34.97	20.46	44.08
Samdrup Jongkhar	15.09	31.09	10.05	37.51	8.20	35.49
Samtse	24.58	28.95	18.30	31.72	16.09	35.47
Sarpang	28.99	21.15	18.72	31.12	13.91	45.86
Thimphu	31.06	24.65	21.49	47.39	17.29	45.01
Trashigang	26.88	26.75	24.31	29.10	19.99	33.24
Trashi Yangtse	30.95	21.81	33.69	21.90	28.27	24.44
Trongsa	27.80	34.89	27.19	54.16	21.66	55.79
Tsirang	18.92	41.17	8.94	62.84	11.49	56.27

Wangdue Phodrang	30.23	17.21	25.21	25.16	20.35	31.12
Zhemgang	21.11	32.52	14.41	42.20	13.04	52.41
Grand Total	589.73	598.60	446.57	780.97	339.59	838.27

Chapter 4: Forest Carbon in different Category

4.2. Forest Class

(i) Carbon density and total estimates by different Forest Class

Carbon Pool	Per ha estimates (tonnes ha^{-1})		Total in million tonnes	
	Broadleaved Forest	Coniferous Forest	Broadleaved Forest	Coniferous Forest
AGB	92.48	90.56	168.28	77.60
BGB	24.26	23.89	44.15	20.48
CWD	2.72	4.22	4.95	3.61
Litter	6.56	9.46	11.94	8.11
SOC	62.65	81.95	114.00	70.22
Total	188.68	210.08	343.32	180.01

1. Above-ground Biomass (AGB)

(i) Total tree Biomass and Carbon Estimate by Forest Class

Forest Class	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	350.08	8.41	320.65	379.52	164.54	8.41	150.71	178.37
Coniferous Forest	158.81	7.96	146.17	171.46	74.64	7.96	68.70	80.58

(ii) Tree Biomass and Carbon per ha estimates by Forest Class

Forest Class	AGB (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	192.39	7.97	177.06	207.72	90.42	7.97	83.22	97.63
Coniferous Forest	185.34	6.95	172.45	198.22	87.11	6.95	81.05	93.16

(iii) Total Sapling Biomass and Carbon Estimate by Forest Class

Forest Class	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	4.82	6.65	4.50	5.14	2.27	6.65	2.12	2.42
Coniferous Forest	4.57	90.68	0.43	8.71	2.15	90.68	0.20	4.10

(iv) Sapling Biomass and Carbon per ha by Forest Class (tonnes ha-1)

Forest Class	AGB (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	2.65	6.08	2.49	2.81	1.25	6.08	1.17	1.32
Coniferous Forest	5.33	90.59	0.50	10.16	2.51	90.59	0.24	4.78

(v) Total estimate of shrub biomass and carbon by Forest Class

Forest Class	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	2.38	23.39	1.82	1.82	1.12	23.39	0.86	0.86
Coniferous Forest	1.34	44.85	0.74	0.74	0.63	44.85	0.35	0.35

(vi) Shrub Biomass and Carbon per ha by Forest Class

Forest Class	AGB (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	1.31	23.39	1.00	1.62	0.62	23.39	0.47	0.76
Coniferous Forest	1.57	44.85	0.86	2.27	0.74	44.85	0.41	1.07

(vii) Total estimate of herb biomass and carbon by Forest Class

Forest Class	AGB (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	0.76	30.68	0.52	0.52	0.36	30.68	0.25	0.25
Coniferous Forest	0.38	35.69	0.24	0.24	0.18	35.69	0.11	0.11

(viii) Herb Biomass and Carbon per ha by Forest Class

Forest Class	AGB (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	0.42	30.68	0.29	0.54	0.20	30.68	0.14	0.26
Coniferous Forest	0.44	35.69	0.28	0.59	0.21	35.69	0.13	0.28

2. Below-ground Biomass (BGB)

(i) Total estimate of tree biomass and carbon by Forest Class

Forest Class	BGB (million tonnes)				BGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	91.93	6.29	86.15	97.71	43.21	6.29	40.49	45.92
Coniferous Forest	42.12	7.44	38.98	45.25	19.80	7.44	18.32	21.27

(ii) Tree biomass and carbon per ha by Forest Class

Forest Class	BGB (tonnes ha^{-1})				BGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	50.52	5.68	47.65	53.39	23.74	5.68	22.39	25.09
Coniferous Forest	49.15	6.35	46.03	52.27	23.10	6.35	21.63	24.57

(iii) Total estimate of sapling biomass and carbon in million tonnes

Forest Class	BGB (million tonnes)				BGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	2.01	5.93	1.89	2.13	0.95	5.93	0.89	1.00
Coniferous Forest	1.45	62.49	0.54	2.35	0.68	62.49	0.26	1.11

(iv) Sapling biomass and carbon per ha by Forest Class

Forest Class	BGB (tonnes ha^{-1})				BGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	1.11	5.28	1.05	1.16	0.52	5.28	0.49	0.55
Coniferous Forest	1.69	62.37	0.64	2.74	0.79	62.37	0.30	1.29

(v) Total estimate of CWD biomass and carbon by Forest Class

Forest Class	CWD Biomass (million tonnes)				CWD Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	10.52	14.21	9.03	12.02	4.95	14.21	4.24	5.65
Coniferous Forest	7.69	20.84	6.09	9.29	3.61	20.84	2.86	4.37

(vi) CWD biomass and carbon per ha by Forest Class

Forest Class	CWD Biomass (tonnes ha^{-1})				CWD Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	5.78	13.96	4.98	6.59	2.72	13.96	2.34	3.10
Coniferous Forest	8.98	20.48	7.14	10.81	4.22	20.48	3.35	5.08

(vii) Total estimate of Litter biomass and carbon by Forest Class

Forest Class	Litter Biomass (million tonnes)				Litter Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	25.41	15.96	21.29	21.29	11.94	15.96	10.01	10.01
Coniferous Forest	17.24	25.76	12.75	12.75	8.11	25.76	5.99	5.99

(viii) Litter biomass and carbon per ha by Forest Class

Forest Class	Litter Biomass (tonnes ha^{-1})				Litter Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	13.96	15.96	11.73	16.19	6.56	15.96	5.52	7.61
Coniferous Forest	20.12	25.76	14.94	25.31	9.46	25.76	7.02	11.90

(ix) Total and per ha estimate of SOC by Forest Class

Forest Class	SOC (tonnes ha^{-1})				SOC (million tonnes)			
	Carbon	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	62.65	8.79	57.14	68.16	114.00	9.19	103.52	124.48
Coniferous Forest	81.95	12.94	71.34	92.55	70.22	13.51	60.73	79.71

4.3 Forest Type

(1) Total Carbon estimate for Different Carbon Pools by Forest Type

Forest Type	AGB	BGB	CWD	Litter	SOC	Total
BPFr	6.02	1.65	0.32	1.42	4.90	14.31
CBFr	92.85	24.05	3.01	5.99	63.25	189.15
CPFr	3.62	1.03	0.13	0.61	2.10	7.49
EOFr	4.80	1.24	0.06	0.23	3.36	9.69
FIFr	49.68	12.96	2.31	4.42	41.27	110.64
HMFr	15.98	4.14	1.05	1.06	12.09	34.32
JRFr	2.53	0.71	0.06	0.27	6.46	10.03
SPFr	4.88	1.25	0.13	0.09	3.83	10.17
STFr	18.26	5.16	0.39	1.95	12.34	38.09
WBFr	56.11	14.62	1.66	3.83	36.86	113.07

(2) Carbon per ha of different carbon pool by Forest Type

Forest Type	AGB	BGB	CWD	Litter	SOC	Total
BPFr	58.18	15.97	3.12	13.74	47.31	138.32
CBFr	123.10	31.89	3.99	7.94	83.86	250.79
CPFr	46.13	13.16	1.64	7.76	26.78	95.47
EOFr	118.14	30.54	1.37	5.68	82.62	238.35
FIFr	114.82	29.95	5.34	10.22	95.40	255.72
HMFr	122.55	31.75	8.05	8.17	92.70	263.21
JRFr	36.23	10.23	0.81	3.90	92.75	143.92
SPFr	115.51	29.62	2.97	2.16	90.60	240.86
STFr	51.28	14.49	1.08	5.46	34.66	106.97
WBFr	83.91	21.86	2.48	5.73	55.13	169.10

(3) Above-ground Biomass

(i) Tree AG Biomass and Carbon per ha by Forest Type

Forest Type	AG Biomass (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	118.74	22.03	92.58	144.90	55.81	22.03	43.51	68.10
CBFr	257.97	5.55	243.65	272.28	121.25	5.55	114.52	127.97
CPFr	94.83	20.91	75.00	114.67	44.57	20.91	35.25	53.89
EOFr	245.69	27.60	177.87	313.52	115.48	27.60	83.60	147.35
FIFr	233.94	7.26	216.96	250.91	109.95	7.26	101.97	117.93
HMFr	256.16	17.07	212.43	299.88	120.39	17.07	99.84	140.95
JRFr	72.48	35.64	46.65	98.32	34.07	35.64	21.92	46.21
SPFr	239.85	27.05	174.96	304.73	112.73	27.05	82.23	143.22
STFr	104.67	7.80	96.51	112.83	49.20	7.80	45.36	53.03
WBFr	173.84	20.60	138.03	209.65	81.70	20.60	64.87	98.53

(ii) Total tree Biomass and Carbon estimate by Forest Type

Forest Type	AG Biomass (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	12.29	22.05	9.58	15.00	5.78	22.05	4.50	7.05
CBFr	194.56	5.94	183.00	206.12	91.44	5.94	86.01	96.88
CPFr	7.44	20.93	5.88	8.99	3.49	20.93	2.76	4.23
EOFr	9.99	27.61	7.23	12.75	4.69	27.61	3.40	5.99
FIFr	101.22	7.46	93.67	108.77	47.57	7.46	44.02	51.12
HMFr	33.41	17.10	27.69	39.12	15.70	17.10	13.02	18.39
JRFr	5.05	35.65	3.25	6.85	2.37	35.65	1.53	3.22
SPFr	10.13	27.06	7.39	12.87	4.76	27.06	3.47	6.05
STFr	37.28	7.96	34.31	40.24	17.52	7.96	16.13	18.91
WBFr	116.24	20.70	92.18	140.30	54.63	20.70	43.32	65.94

(iii) Sapling Biomass and Carbon per ha by Forest Type

Forest Type	AG Biomass (tonnes ha^{-1})				AGB Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	2.33	30.86	1.61	3.05	1.10	30.86	0.76	1.43
CBFr	2.56	9.83	2.31	2.82	1.21	9.83	1.09	1.32
CPFr	1.86	28.57	1.33	2.39	0.87	28.57	0.62	1.12
EOFr	4.47	38.61	2.75	6.20	2.10	38.61	1.29	2.91
FIFr	8.53	121.45	(1.83)	18.90	4.01	121.45	(0.86)	8.88
HMFr	2.91	31.91	1.98	3.83	1.37	31.91	0.93	1.80

JRFr	3.29	54.39	1.50	5.08	1.55	54.39	0.70	2.39
SPFr	2.22	52.20	1.06	3.39	1.05	52.20	0.50	1.59
STFr	2.42	7.93	2.23	2.61	1.14	7.93	1.05	1.23
WBFr	2.74	10.88	2.45	3.04	1.29	10.88	1.15	1.43

(iv) Total AG Biomass and carbon estimate for sapling by Forest Type

Forest Type	AG Biomass (tonnes)				AGB Carbon (tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	0.24	30.87	0.17	0.32	0.11	30.87	0.08	0.15
CBFr	1.93	10.06	1.74	2.13	0.91	10.06	0.82	1.00
CPFr	0.15	28.58	0.10	0.19	0.07	28.58	0.05	0.09
EOFr	0.18	38.62	0.11	0.25	0.09	38.62	0.05	0.12
FIFr	3.69	121.46	(0.79)	8.18	1.74	121.46	(0.37)	3.84
HMFr	0.38	31.92	0.26	0.50	0.18	31.92	0.12	0.23
JRFr	0.23	54.39	0.10	0.35	0.11	54.39	0.05	0.17
SPFr	0.09	52.21	0.04	0.14	0.04	52.21	0.02	0.07
STFr	0.86	8.09	0.79	0.93	0.41	8.09	0.37	0.44
WBFr	1.84	11.08	1.63	2.04	0.86	11.08	0.77	0.96

(v) Shrub Biomass and Carbon per ha by Forest Type

Forest Type	Shrub Biomass (tonnes ha^{-1})				Shrub Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	2.29	75.44	0.56	4.02	1.08	75.44	0.26	1.89
CBFr	1.09	44.59	0.60	1.58	0.51	44.59	0.28	0.74
CPFr	0.36	50.69	0.18	0.54	0.17	50.69	0.08	0.25
EOFr	0.38	117.77	(0.07)	0.83	0.18	117.77	(0.03)	0.39
FIFr	1.55	71.83	0.44	2.66	0.73	71.83	0.20	1.25
HMFr	1.51	147.49	(0.72)	3.75	0.71	147.49	(0.34)	1.76
JRFr	0.83	80.68	0.16	1.51	0.39	80.68	0.08	0.71
SPFr	2.44	77.27	0.56	4.33	1.15	77.27	0.26	2.04
STFr	1.52	39.12	0.93	2.12	0.71	39.12	0.44	0.99
WBFr	1.44	37.45	0.90	1.98	0.68	37.45	0.42	0.93

(vi) Total estimates for Shrub Biomass and Carbon by Forest Type

Forest Type	AG Biomass (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	0.24	75.44	0.24	0.24	0.11	75.44	0.03	0.20
CBFr	0.82	44.64	0.82	0.82	0.39	44.64	0.21	0.56

CPFr	0.03	50.70	0.03	0.03	0.01	50.70	0.01	0.02
EOFr	0.02	117.77	0.02	0.02	0.01	117.77	(0.00)	0.02
FIFr	0.67	71.85	0.67	0.67	0.31	71.85	0.09	0.54
HMFr	0.20	147.49	0.20	0.20	0.09	147.49	(0.04)	0.23
JRFr	0.06	80.69	0.06	0.06	0.03	80.69	0.01	0.05
SPFr	0.10	77.27	0.10	0.10	0.05	77.27	0.01	0.09
STFr	0.54	39.15	0.54	0.54	0.25	39.15	0.15	0.35
WBFr	0.96	37.50	0.96	0.96	0.45	37.50	0.28	0.62

(vii) Herb Biomass and Carbon per ha by Forest Type

Forest Type	Herb Biomass (tonnes ha^{-1})				Herb Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	0.43	79.73	0.09	0.76	0.20	79.73	0.04	0.36
CBFr	0.30	26.29	0.22	0.38	0.14	26.29	0.10	0.18
CPFr	1.09	78.33	0.24	1.95	0.51	78.33	0.11	0.92
EOFr	0.82				0.39			
FIFr	0.29	61.34	0.11	0.46	0.13	61.34	0.05	0.22
HMFr	0.16	82.99	0.03	0.29	0.07	82.99	0.01	0.14
JRFr	0.49	66.14	0.17	0.81	0.23	66.14	0.08	0.38
SPFr	1.26	89.06	0.14	2.38	0.59	89.06	0.06	1.12
STFr	0.50	43.45	0.28	0.71	0.23	43.45	0.13	0.33
WBFr	0.50	61.18	0.19	0.81	0.24	61.18	0.09	0.38

(viii) Total estimates for Herb Biomass and Carbon by Forest Type

Forest Type	AG Biomass (million tonnes)				AGB Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	0.04	79.73	0.01	0.08	0.02	79.73	0.00	0.04
CBFr	0.22	26.38	0.17	0.28	0.11	26.38	0.08	0.13
CPFr	0.09	78.33	0.02	0.15	0.04	78.33	0.01	0.07
EOFr	0.03		0.00	0.00	0.02		0.00	0.00
FIFr	0.12	61.37	0.05	0.20	0.06	61.37	0.02	0.09
HMFr	0.02	82.99	0.00	0.04	0.01	82.99	0.00	0.02
JRFr	0.03	66.14	0.01	0.06	0.02	66.14	0.01	0.03
SPFr	0.05	89.06	0.01	0.10	0.03	89.06	0.00	0.05
STFr	0.18	43.48	0.10	0.25	0.08	43.48	0.05	0.12
WBFr	0.34	61.21	0.13	0.54	0.16	61.21	0.06	0.25

4. Below-ground Biomass (BGB)

(i) Tree Biomass and Carbon per ha by Forest Type

Forest Type	BG Biomass (tonnes ha-1)				BGB Carbon (tonnes ha-1)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	33.03	18.79	26.83	39.24	15.52	18.79	12.61	18.44
CBFr	66.78	4.97	63.46	70.10	31.39	4.97	29.83	32.95
CPFr	27.22	18.45	22.20	32.24	12.79	18.45	10.43	15.15
EOFr	63.23	25.24	47.27	79.19	29.72	25.24	22.22	37.22
FIFr	61.27	6.65	57.19	65.34	28.80	6.65	26.88	30.71
HMFr	66.37	15.55	56.05	76.68	31.19	15.55	26.34	36.04
JRFr	20.53	31.81	14.00	27.07	9.65	31.81	6.58	12.72
SPFr	62.12	24.79	46.72	77.52	29.20	24.79	21.96	36.43
STFr	29.79	6.99	27.71	31.87	14.00	6.99	13.02	14.98
WBFr	45.38	13.61	39.20	51.56	21.33	13.61	18.42	24.23

(ii) Total estimates for tree BG Biomass and Carbon by Forest Type

Forest Type	BG Biomass (tonnes)				BGB Carbon (tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	3.42	18.81	2.78	4.06	1.61	18.81	1.30	1.91
CBFr	50.36	5.41	47.64	53.09	23.67	5.41	22.39	24.95
CPFr	2.13	18.46	1.74	2.53	1.00	18.46	0.82	1.19
EOFr	2.57	25.24	1.92	3.22	1.21	25.24	0.90	1.51
FIFr	26.51	6.88	24.69	28.33	12.46	6.88	11.60	13.32
HMFr	8.65	15.58	7.31	10.00	4.07	15.58	3.43	4.70
JRFr	1.43	31.82	0.98	1.89	0.67	31.82	0.46	0.89
SPFr	2.62	24.80	1.97	3.27	1.23	24.80	0.93	1.54
STFr	10.61	7.17	9.85	11.37	4.99	7.17	4.63	5.34
WBFr	30.34	13.77	26.17	34.52	14.26	13.77	12.30	16.22

(iii) Sapling Biomass and Carbon per ha by Forest Type

Forest Type	BG Biomass (tonnes ha-1)				BGB Carbon (tonnes ha-1)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	0.95	27.63	0.69	1.21	0.45	27.63	0.32	0.57
CBFr	1.07	8.72	0.97	1.16	0.50	8.72	0.46	0.55
CPFr	0.79	26.14	0.59	1.00	0.37	26.14	0.28	0.47
EOFr	1.75	35.00	1.14	2.36	0.82	35.00	0.53	1.11
FIFr	2.46	91.76	0.20	4.71	1.15	91.76	0.10	2.21
HMFr	1.18	29.04	0.84	1.52	0.55	29.04	0.39	0.71
JRFr	1.24	48.94	0.63	1.84	0.58	48.94	0.30	0.87

SPFr	0.91	47.44	0.48	1.34	0.43	47.44	0.22	0.63
STFr	1.04	7.15	0.97	1.12	0.49	7.15	0.45	0.52
WBFr	1.14	9.36	1.03	1.24	0.53	9.36	0.48	0.58

5. Coarse Woody Debris

(i) CWD Biomass and carbon per ha by Forest Type

Forest Class	CWD Biomass (tonnes ha-1)				CWD Carbon (tonnes ha-1)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	6.64	43.67	3.74	9.53	3.12	43.67	1.76	4.48
CBFr	8.50	18.68	6.91	10.08	3.99	18.68	3.25	4.74
CPFr	3.50	91.33	0.30	6.69	1.64	91.33	0.14	3.15
EOFr	2.92	88.18	0.35	5.49	1.37	88.18	0.16	2.58
FIFr	11.36	24.10	8.62	14.10	5.34	24.10	4.05	6.63
HMFr	17.13	62.71	6.39	27.88	8.05	62.71	3.00	13.10
JRFr	1.72	74.96	0.43	3.01	0.81	74.96	0.20	1.42
SPFr	6.31	50.28	3.14	9.49	2.97	50.28	1.48	4.46
STFr	2.30	35.66	1.48	3.12	1.08	35.66	0.70	1.47
WBFr	5.27	24.28	3.99	6.55	2.48	24.28	1.87	3.08

(ii) Total estimates for biomass and carbon by Forest Type

Forest Class	CWD Biomass (million tonnes)				CWD Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	0.69	43.68	0.39	0.99	0.32	43.68	0.18	0.46
CBFr	6.41	18.80	5.20	7.61	3.01	18.80	2.45	3.58
CPFr	0.27	91.34	0.02	0.52	0.13	91.34	0.01	0.25
EOFr	0.12	88.18	0.01	0.22	0.06	88.18	0.01	0.10
FIFr	4.92	24.16	3.73	6.10	2.31	24.16	1.75	2.87
HMFr	2.23	62.72	0.83	3.64	1.05	62.72	0.39	1.71
JRFr	0.12	74.97	0.03	0.21	0.06	74.97	0.01	0.10
SPFr	0.27	50.29	0.13	0.40	0.13	50.29	0.06	0.19
STFr	0.82	35.70	0.53	1.11	0.39	35.70	0.25	0.52
WBFr	3.52	24.37	2.66	4.38	1.66	24.37	1.25	2.06

6. Litter

(i) Litter Biomass and Carbon per ha by Forest Type

Forest Class	Litter Biomass (tonnes ha^{-1})				Litter Carbon (tonnes ha^{-1})			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	29.23	72.03	8.17	50.28	13.74	72.01	3.85	23.63
CBFr	16.90	21.84	13.21	20.59	7.94	21.84	6.21	9.68
CPFr	16.51	75.88	3.98	29.04	7.76	75.86	1.87	13.65
EOFr	12.09	171.22	(8.61)	32.78	5.68	171.21	(4.04)	15.40
FIFr	21.73	32.06	14.77	28.70	10.22	32.05	6.94	13.49
HMFr	17.38	48.58	8.93	25.82	8.17	48.57	4.20	12.13
JRFr	8.29	56.34	3.62	12.96	3.90	56.26	1.71	6.09
SPFr	4.58	123.15	(1.06)	10.23	2.16	122.88	(0.49)	4.81
STFr	11.62	49.11	5.91	17.33	5.46	49.10	2.78	8.14
WBFr	12.18	22.73	9.41	14.95	5.73	22.73	4.43	7.03

(ii) Total estimates for Litter Biomass and Carbon by Forest Type

Forest Class	Litter Biomass (million tonnes)				Litter Carbon (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	3.02	72.04	0.85	5.20	1.42	72.02	0.40	2.45
CBFr	12.75	21.94	9.95	15.54	5.99	21.94	4.68	7.31
CPFr	1.29	75.89	0.31	2.28	0.61	75.87	0.15	1.07
EOFr	0.49	171.22	(0.35)	1.33	0.23	171.21	(0.16)	0.63
FIFr	9.40	32.10	6.38	12.42	4.42	32.10	3.00	5.84
HMFr	2.27	48.59	1.16	3.37	1.06	48.58	0.55	1.58
JRFr	0.58	56.35	0.25	0.90	0.27	56.27	0.12	0.42
SPFr	0.19	123.16	(0.04)	0.43	0.09	122.88	(0.02)	0.20
STFr	4.14	49.13	2.10	6.17	1.95	49.12	0.99	2.90
WBFr	8.15	22.82	6.29	10.01	3.83	22.82	2.96	4.70

7. Soil Organic Carbon

(i) SOC per ha in SOC by Forest Type

Forest Type	SOC (tonnes ha^{-1})				SOC (tonnes ha^{-1})			
	Carbon	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	47.31	31.95	32.20	62.42	4.90	31.96	3.33	6.46
CBFr	83.86	9.87	75.58	92.14	63.25	10.10	56.86	69.64
CPFr	26.78	65.98	9.11	44.44	2.10	65.99	0.71	3.48
EOFr	82.62	67.76	26.64	138.60	3.36	67.76	1.08	5.63
FIFr	95.40	16.45	79.70	111.09	41.27	16.54	34.45	48.10

HMFr	92.70	25.80	68.78	116.61	12.09	25.82	8.97	15.21
JRFr	92.75	18.56	75.54	109.96	6.46	18.57	5.26	7.66
SPFr	90.60	18.55	73.80	107.41	3.83	18.55	3.12	4.54
STFr	34.66	20.95	27.39	41.92	12.34	21.01	9.75	14.93
WBFr	55.13	14.30	47.24	63.01	36.86	14.45	31.54	42.19

(ii) Total SOC in different soil layer by Forest Type (million tonnes)

Forest Type	0-10 cm		10-20 cm		20-30 cm	
	SOC	MoE (%)	SOC	MoE (%)	SOC	MoE (%)
BPFr	2.87	28.37	1.26	38.75	0.77	46.46
CBFr	25.12	10.84	21.18	12.31	16.96	14.12
CPFr	1.12	67.01	0.59	72.80	0.38	62.08
EOFr	1.10	56.62	1.35	83.39	0.91	74.56
FIFr	15.83	18.93	14.92	23.60	10.52	18.15
HMFr	4.42	17.15	3.79	47.77	3.88	38.55
JRFr	2.40	37.26	2.22	20.79	1.84	32.46
SPFr	1.95	27.87	1.16	22.60	0.71	68.06
STFr	6.08	23.82	3.68	25.10	2.59	24.44
WBFr	17.17	14.32	10.95	16.50	8.74	20.40

(iii) SOC per ha in different soil layer by Forest Type

Forest Type	0-10 cm		10-20 cm		20-30 cm	
	SOC	MoE (%)	SOC	MoE (%)	SOC	MoE (%)
BPFr	27.72	28.36	12.19	38.74	7.39	46.45
CBFr	33.30	10.63	28.08	12.12	22.48	13.96
CPFr	14.35	67.00	7.54	72.80	4.88	62.07
EOFr	27.00	56.62	33.32	83.39	22.30	74.56
FIFr	36.59	18.85	34.48	23.54	24.32	18.07
HMFr	33.91	17.12	29.06	47.76	29.73	38.53
JRFr	34.46	37.25	31.89	20.77	26.39	32.45
SPFr	46.27	27.86	27.53	22.59	16.81	68.06
STFr	17.07	23.77	10.33	25.05	7.26	24.38
WBFr	25.68	14.18	16.38	16.37	13.08	20.30

Chapter 5: Biomass Growth and Increment

1. Total estimate for Biomass and Carbon Increment by Dzongkhag

Dzongkhag	AGB Increment (million tonnes)				AGBC Increment (million tonnes)			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	0.30	36.53	0.19	0.41	0.14	36.53	0.09	0.19
Chhukha	0.34	51.39	0.17	0.52	0.16	51.39	0.08	0.24
Dagana	0.42	22.74	0.32	0.51	0.20	22.74	0.15	0.24
Gasa	0.06	35.09	0.04	0.09	0.03	35.09	0.02	0.04
Haa	0.20	36.74	0.12	0.27	0.09	36.74	0.06	0.13
Lhuentse	0.18	69.50	0.05	0.30	0.08	69.50	0.03	0.14
Mongar	0.38	57.62	0.16	0.59	0.18	57.62	0.08	0.28
Paro	0.24	45.30	0.13	0.35	0.11	45.30	0.06	0.17
Pemagatshel	0.47	70.56	0.14	0.80	0.22	70.56	0.06	0.38
Punakha	0.30	38.40	0.18	0.41	0.14	38.40	0.09	0.19
Samdrup Jongkhar	0.44	30.98	0.30	0.57	0.21	30.98	0.14	0.27
Samtse	0.17	27.17	0.13	0.22	0.08	27.17	0.06	0.10
Sarpang	0.32	23.66	0.25	0.40	0.15	23.66	0.12	0.19
Thimphu	0.21	31.36	0.14	0.28	0.10	31.36	0.07	0.13
Trashi Yangtse	0.17	45.84	0.09	0.25	0.08	45.84	0.04	0.12
Trashigang	0.44	26.91	0.32	0.56	0.21	26.91	0.15	0.26
Trongsa	0.23	39.48	0.14	0.32	0.11	39.48	0.07	0.15
Tsirang	0.19	46.12	0.10	0.27	0.09	46.12	0.05	0.13
Wangdue Phodrang	0.47	23.91	0.36	0.58	0.22	23.91	0.17	0.27
Zhemgang	0.86	33.14	0.58	1.15	0.41	33.14	0.27	0.54

2. Biomass and Carbon Increment by Dzongkhag

Dzongkhag	AGB Increment				AGB Carbon Increment			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Bumthang	0.30	36.53	0.19	0.41	0.14	36.53	0.09	0.19
Chhukha	0.34	51.39	0.17	0.52	0.16	51.39	0.08	0.24
Dagana	0.42	22.74	0.32	0.51	0.20	22.74	0.15	0.24
Gasa	0.06	35.09	0.04	0.09	0.03	35.09	0.02	0.04
Haa	0.20	36.74	0.12	0.27	0.09	36.74	0.06	0.13
Lhuentse	0.18	69.50	0.05	0.30	0.08	69.50	0.03	0.14
Mongar	0.38	57.62	0.16	0.59	0.18	57.62	0.08	0.28
Paro	0.24	45.30	0.13	0.35	0.11	45.30	0.06	0.17
Pemagatshel	0.47	70.56	0.14	0.80	0.22	70.56	0.06	0.38
Punakha	0.30	38.40	0.18	0.41	0.14	38.40	0.09	0.19
Samdrup Jongkhar	0.44	30.98	0.30	0.57	0.21	30.98	0.14	0.27
Samtse	0.17	27.17	0.13	0.22	0.08	27.17	0.06	0.10

Sarpang	0.32	23.66	0.25	0.40	0.15	23.66	0.12	0.19
Thimphu	0.21	31.36	0.14	0.28	0.10	31.36	0.07	0.13
Trashi Yangtse	0.17	45.84	0.09	0.25	0.08	45.84	0.04	0.12
Trashigang	0.44	26.91	0.32	0.56	0.21	26.91	0.15	0.26
Trongsa	0.23	39.48	0.14	0.32	0.11	39.48	0.07	0.15
Tsirang	0.19	46.12	0.10	0.27	0.09	46.12	0.05	0.13
Wangdue Phodrang	0.47	23.91	0.36	0.58	0.22	23.91	0.17	0.27
Zhemgang	0.86	33.14	0.58	1.15	0.41	33.14	0.27	0.54

3. Total estimate for Biomass and Carbon Increment by Forest Type

Forest Class	AGB Increment				AGB Carbon Increment			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
BPFr	0.36	45.06	0.20	0.52	0.17	45.06	0.09	0.24
CBFr	1.60	14.47	1.37	1.84	0.75	14.47	0.64	0.86
CPFr	0.14	51.41	0.07	0.22	0.07	51.41	0.03	0.10
EOFr	0.03	64.59	0.01	0.05	0.01	64.59	0.01	0.02
FIFr	0.95	23.67	0.72	1.17	0.45	23.67	0.34	0.55
HMFr	0.32	39.37	0.19	0.44	0.15	39.37	0.09	0.21
JRFr	0.04	60.43	0.02	0.06	0.02	60.43	0.01	0.03
SPFr	0.14	77.59	0.03	0.24	0.06	77.59	0.01	0.11
STFr	1.05	26.09	0.77	1.32	0.49	26.09	0.36	0.62
WBFr	1.87	18.18	1.53	2.20	0.88	18.18	0.72	1.04

3. Total estimate for Biomass and Carbon Increment by Forest Type

Elevation (m.a.s.l)	AGB Increment				AGB Carbon Increment			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
<1000	1.05	27.23	0.76	1.33	0.49	27.23	0.36	0.63
1000-2000	2.12	18.36	1.73	2.51	1.00	18.36	0.81	1.18
2000-3000	2.06	15.39	1.75	2.38	0.97	15.39	0.82	1.12
3000-4000	1.28	18.72	1.04	1.52	0.60	18.72	0.49	0.71
>=4000	0.03	61.69	0.01	0.04	0.01	61.69	0.00	0.02

4. Total estimate for Biomass and Carbon Increment by Species

Forest Class	AGB Increment				AGB Carbon Increment			
	Biomass	MoE (%)	Lower Limit	Upper Limit	Carbon	MoE (%)	Lower Limit	Upper Limit
Abies densa	0.44	35.51	0.28	0.59	0.21	35.51	0.13	0.28
Acer spp.	0.15	34.88	0.10	0.21	0.07	34.88	0.05	0.10

Ailanthus integrifolia	0.01	132.09	0.00	0.02	0.00	132.09	0.00	0.01
Alnus spp.	0.12	70.08	0.04	0.21	0.06	70.08	0.02	0.10
Aphanamixis polystachya	0.01	138.74	0.00	0.02	0.00	138.74	0.00	0.01
Beilschmiedia spp.	0.12	58.44	0.05	0.19	0.06	58.44	0.02	0.09
Betula spp.	0.14	79.85	0.03	0.24	0.06	79.85	0.01	0.11
Castanopsis spp.	0.33	57.75	0.14	0.51	0.15	57.75	0.06	0.24
Cupressus spp.	0.01	200.01	(0.01)	0.04	0.01	200.01	(0.01)	0.02
Duabanga grandiflora	0.00	200.01	0.00	0.00	0.00	200.01	0.00	0.00
Engelhardtia spicata	0.14	66.90	0.05	0.24	0.07	66.90	0.02	0.11
Exbucklandia populnea	0.04	86.42	0.01	0.08	0.02	86.42	0.00	0.04
Juglans regia	0.01	181.17	(0.01)	0.04	0.01	181.17	(0.01)	0.02
Juniperus spp.	0.09	59.86	0.04	0.14	0.04	59.86	0.02	0.07
Larix griffithii	0.01	191.40	0.00	0.01	0.00	191.40	0.00	0.01
Magnolia spp.	0.04	82.25	0.01	0.07	0.02	82.25	0.00	0.03
Persea spp.	0.21	32.05	0.14	0.28	0.10	32.05	0.07	0.13
Phoebe goalparensis	0.01	143.84	0.00	0.01	0.00	143.84	0.00	0.01
Picea spinulosa	0.12	67.29	0.04	0.21	0.06	67.29	0.02	0.10
Pinus roxburghii	0.07	85.88	0.01	0.13	0.03	85.88	0.00	0.06
Pinus wallichiana	0.31	71.41	0.09	0.52	0.14	71.41	0.04	0.25
Quercus spp.	0.64	43.97	0.36	0.92	0.30	43.97	0.17	0.43
Rhododendron spp.	0.29	30.43	0.20	0.38	0.14	30.43	0.09	0.18
Schima wallichii	0.14	44.52	0.08	0.20	0.07	44.52	0.04	0.10
Sterculia villosa	0.01	200.01	(0.01)	0.03	0.00	200.01	0.00	0.01
Symplocos spp.	0.11	36.85	0.07	0.16	0.05	36.85	0.03	0.07
Taxus baccata	0.01	131.20	0.00	0.03	0.01	131.20	0.00	0.02
Terminalia myriocarpa	0.01	200.01	(0.01)	0.03	0.00	200.01	0.00	0.01
Tetrameles nudiflora	0.03	200.01	(0.03)	0.10	0.02	200.01	(0.02)	0.05
Tsuga dumosa	0.16	66.16	0.05	0.26	0.07	66.16	0.02	0.12
Others	2.63	14.38	2.25	3.01	1.24	14.38	1.06	1.41

9. Annexure

9.1 Biomass equation

Species	Equations	t1	t2	t3
Abies densa	(-5.76 + 3436.28 * ba + 36408.9 * X2)	0.004562064	0.110446617	0.303648439
Acer campbelli	-6.193+3363.796ba + 11419.843X2	0.0075	0.123	0.3454
Alnus nepalensis	(-12.349 + 5473.896 * ba + 1581.599 * X2)	0.008812246	0.131185153	0.415137691
Beilschmiedia sikki-mensis	-3.27 + 4225.01ba + 39584.15X2	0.00537	0.1302	0.38761
Betula utilis	(-9.146 + 4644.714 * ba + 14990.383 * X2)	0.0084	0.145	0.504
Bombax ceiba	-10.38 + 2556.147ba + 19524.442X2	0.0084	0.1205	0.42
Castanopsis hystrix	-11.813 + 4895.414ba + 23641.652X2	0.0084	0.1304	0.44711
Castanopsis tribulnoides	1.39+5303*ba+2722X-2+4129*X3	0.007382271	0.134038	0.4022201
Cupressus corneyana	(-3.96 + 4300.38 * ba + 50295.83 * X2)	0.003904686	0.098999438	0.378530499
Daphnephyllum himalaynse	0.635 + 3953.1ba + 12659.447 X2	0.0065	0.1182	0.3794
Daubangga grandiflora	-8.547 + 3304.965ba - 615.336X2	0.0081	0.1205	0.419
Engelhardia spicata	(-10.095 + 4803.727 * ba + 16746.746 * X2)	0.00719	0.1319	0.38867
Juniperus recurva	(-4.848 + 3233.975 * ba + 26753.127 * X2)	0.006816078	0.075555303	0.26393533
Larix griffithii	(-3.836 + 3454.557 * ba + 29738.552 * X2)	0.008395906	0.131147749	0.330316869
Macaranga denticulata	2.316 + 4550.87ba + 9441.743X2	0.0084	0.105	0.3474
Michelia velutina	0.136 + 4631.542ba + 6188.159X2	0.0074	0.1285	0.4376
Persea clarkeana	-7.248 + 4421.948ba + 20216.06X2	0.007918777	0.129176399	0.400918198
Persea fructifera	(-6.02 + 4283.85 * ba + 38065.80 * X2)	0.0081	0.1155	0.3735
Phoebe hainesiana	(-4.853 + 3830.825 * ba + 12046.560 * X2)	0.00621	0.12165	0.37724
Picea spinulosa	(-6.16 + 3933.61 * ba + 43569.11 * X2)	0.00664761	0.11341149	0.32123374
Pinus roxburghii	(-3.44 + 5097.67 * ba + 56375.66 * X2)	0.0023	0.1029	0.3685285
Pinus wallichiana	(-1.57 + 3444.3 * ba + 55392.17 * X2)	0.00309	0.09840699	0.39491075

Populus ciliata	(-5.284 + 3422.390 * ba + 26076.738 * X2)	0.00709	0.1324	0.39604
Quercus glauca	(-3.97 + 6436.76 * ba + 36959.82 * X2)	0.006535691	0.099043421	0.374257305
Quercus griffithii	(-9.382 + 5438.023 * ba + 15835.176 * X2)	0.007310172	0.1321385	0.3649982
Quercus lamellosa	(-5.92 + 5100.42 * ba + 35818.84 * X2	0.00613	0.1234	0.40978
Quercus lanata	(-0.774 + 4499.805 * ba + 25308.290 * X2)	0.01333473	0.1418822	0.3939557
Quercus semicarpifolia	-6.44 + 6142.21ba + 35628.42X2	0.0051	0.12	0.4326
Rhododendron arbo-reum	(-0.19 + 1636.54 * ba + 43190.03 * X2)	0.006834221	0.09186331	0.2073393
Rhododendron grande	-1.043 +3016.555ba + 22880.28X2	0.00671	0.1312	0.37984
Schima wallichii	(-6.81 + 4154.46 * ba +31801.28 *X2)	0.0087	0.1345	0.3274
Symplocos ramosissima	-1.9+2744.9ba + 545721.9X2	0.0468	0.77	2.1848
Symplocos sumuntia	-3.32 + 3030ba + 36338.26X2	0.006	0.086	0.273
General conifer	(-12.3 3299 * ba + 52756 * X2)	0.004927274	0.107521009	0.369822475
Teminalia tomentosa	-29.534 + 7963.614ba - 14211.634X2	0.0065	0.1225	0.3837
Tsuga dumosa	(-4.798 + 3853.768 * ba + 15174.671 * X2)	0.006180612	0.138544236	0.440845246
General broadleaf	-1.06+4341*ba+30173X-2+4013*X3	0.00664761	0.1194591	0.3689771

9.2 List of Team members

1. Overall Coordinator and Principal Coordinator of the NFI

SN	Name	Designation	Office	Remarks
		Overall Coordinators of the NFI		
1	Lobzang Dorji	Hon'ble Director	DoFPS	
2	Norbu Wangdi	Chief Forestry Officer	FRMD	2020-June 2021
3	Sonam Tobgay	Chief Forestry Officer	FRMD	July 2021-December 2022
4	Kinley Tshering	Chief Forestry Officer	FMID	January 2023-May 2023
5	Kinley Dem	Offtg. Chief Forestry Officer	FMID	May 2023-
		Principal Coordinator of the NFI		
1	Dorji Wangdi	Principal Forestry Officer	FMID	
2	Kinley Dem	Deputy. Chief Forestry Officer	FMID	January 2021-
3	Yonten Phuntsho	Deputy. Chief Forestry Officer	FRMD	2020

2. Principal Coordinators of NFI Field work

SN	Name	Designation	Office
1	Pankey Dukpa	Chief Forestry Officer	Bumthang FD
3	Sithup Lhendup	Chief Forestry Officer	BWS
4	Kencho Dukpa	Chief Forestry Officer	Dagana Forest Division
5	Pema Wangda	Chief Forestry Officer	Gedu FD
6	Rinzin Dorji	Chief Forestry Officer	JDNP
7	Tashi Tobgyel	Chief Forestry Officer	JSWNP
8	Ugyen Tshering	Chief Forestry Officer	JWS
9	Karma Tempa	Chief Forestry Officer	Mongar FD
10	Lhendup Tharchen	Chief Forestry Officer	Paro FD
11	Ugyen Wangchuk	Chief Forestry Officer	JKSNR
2	Tshering Dhendup	Chief Forestry Officer	Pemgatshel FD
12	Yonten Norbu	Chief Forestry Officer	PNP
13	Dorji Rabten	Chief Forestry Officer	PWS
14	Samten Wangchuk	Chief Forestry Officer	RMNP
15	Sangay Dorji	Chief Forestry Officer	Samdrup Jongkhar Division
16	Sonam Wangchuk	Chief Forestry Officer	Samtse FD
17	Phub Dhendup	Chief Forestry Officer	Sarpang FD
18	Wangchuk Doji	Chief Forestry Officer	SWS
19	Gyeltshen Dukpa	Chief Forestry Officer	Thimphu Division
20	Karma Leki	Chief Forestry Officer	Trashigang FD
21	Dimple Thapa	Chief Forestry Officer	Tsirang FD
22	Karma Tenzin	Chief Forestry Officer	Wangdi FD
23	Tshering Dendhup	Chief Forestry Officer	WCNP
24	Jigme Dorji	Chief Forestry Officer	Zhemgang FD

3. List of NFI crew member

Name	Designation	Office	Remarks
Tshering Norbu	Forest Ranger II	Bumthang FD	Crew Leader
Dorji Drakpa	FR-I	Bumthang FD	Crew Member
Tshering Chophel	Sr. Fr	Bumthang FD	Crew Member
Dorji Tshewang	Sr.Fr	Bumthang FD	Crew Member
Rinchen Dorji	Sr. Forester	Bumthang FD	Crew Member
Lhakpa Tshering	Sr.Forest Ranger I	BWS	Crew Leader
Tek Bdr Rai	Forestry Officer	BWS	Crew Member
Tshering Nidup	Sr.Forest Ranger III	BWS	Crew Member
Jamyangla	Sr. Forester	BWS	Crew Member
Rinchen Dorji	Sr. Forester	BWS	Crew Member
Ugyen Tenzin	Forestry Officer	Dagana FD	Crew Leader
Karna Bdr Ghalley	Sr. Forester	Dagana FD	Crew Member
Pema Jamtsho	Forest Ranger II	Dagana FD	Crew Member

L.B Tamang	Forest Ranger I	Dagana FD	Crew Member
Nima Tshering Tamang	Forester	Dagana FD	Crew Member
Phub Tshering	Sr. Forest Ranger	Gedu FD	Crew Leader
Nima Dorji	Sr. Forester	Gedu FD	Crew Member
Sonam Tenzin	Sr. Forester	Gedu FD	Crew Member
Norbu Gyeltshen	Sr. Forester	Gedu FD	Crew Member
Ashman Tamang	Sr. Forester	Gedu FD	Crew Member
Norbu	Forest Ranger I	JDNP	Crew Leader
Karma Gyeltshen	Sr. Forester	JDNP	Crew Member
Dorji Wangchuk	Sr. Forester	JDNP	Crew Member
Namgay Dorji	Sr. Forester	JDNP	Crew Member
Yenten Jamtsho	Forest Ranger II	JDNP	Crew Member
Kelzang Thinley	Forest Ranger II	JDNP	Crew Leader
Thinley Dorji	Forest Ranger II	JDNP	Crew Member
Bishnu Kumar Ghalley	Sr. Forester	JDNP	Crew Member
Nidup Dorji	Forest Ranger I	JDNP	Crew Member
Sangay Penjor	Sr. Forester	JDNP	Crew Member
Dophu	Sr. Forest Ranger III	JKSNR	Crew Leader
Wangchuk	Sr. Forester	JKSNR	Crew Member
Tshewang Namgay	Forest Ranger II	JKSNR	Crew Member
Sangay Gyeltshen	Forest Ranger II	JKSNR	Crew Member
Guman Singh Biswa	Sr. Forester	JKSNR	Crew Member
Cheku	Forest Ranger I	JSWNP	Crew Leader
Tshering Wangchuk	Sr. Forester	JSWNP	Crew Member
Singye	Sr. Forester	JSWNP	Crew Member
Sangay Lhajay	Forest Ranger II	JSWNP	Crew Member
Pema Namgyel	Sr. Forester	JSWNP	Crew Member
Sonam Tobgay	Sr. Forest Ranger III	JWS	Crew Leader/ Data Manager
Karma Nidup	Forest Ranger I	JWS	Crew Member
Chandra Lal Gautum	Sr. Forester	JWS	Crew Member
Kinley Gyeltshen	Sr. Forester	JWS	Crew Member
Tashi	Sr. Forester	JWS	Crew Member
Tshering Wangdi	Sr. Forester	JWS	Crew Member/ Asst Data Manager
Pema Rigzin	Sr. Forest Ranger III	Mongar FD	Crew Leader
Tshewang Tenzin	Forest Ranger I	Mongar FD	Crew Member
Gembo Tshering	Sr. Forester	Mongar FD	Crew Member
Dawa Norbu	Sr. Forester	Mongar FD	Crew Member
Nima Gyeltshen	Forester	Mongar FD	Crew Member
Tenzin Jamtsho	Forest Ranger I	Paro FD	Crew Leader
Chogyel	Sr. Forester	Paro FD	Crew Member
Narish Kumar Rai	Sr. Forester	Paro FD	Crew Member

Lhab Tshering	Sr. Forester	Paro FD	Crew Member
Tshering Wangchuk	Sr. Forester	Paro FD	Crew Member
Rabten	Forestry Officer	Pemagatshel FD	Crew Leader
Sungrab Dorji	Forest Ranger II	Pemagatshel FD	Crew Member
Cheki	Sr. Forester	Pemagatshel FD	Crew Member
Phuntsho Norbu	Forestry Officer	Pemagatshel FD	Crew Member
Pema Dorji	Forest Ranger I	Pemagatshel FD	Crew Member
Chedup	Sr. Forester	Pemagatshel FD	Crew Member
Nima Wangdi	Forest Ranger II	Pemagatshel FD	Crew Member/ Asst Data Manager
Kinley Penjor	Forest Ranger I	Pemagatshel FD	Crew Leader
Tshewang Namgay	Sr. Forester	Pemagatshel FD	Crew Member
Phuntsho Namgay	Forest Ranger I	PNP	Crew Member
Ugyen Tshewang	Forest Ranger II	PNP	Crew Leader
Wangda Jatsho	Sr. Forester	PNP	Crew Member
Tashi Samdrup	Sr. Forester	PNP	Crew Member
Sonam Choeda	Sr. Forester	PNP	Crew Member
Tshewang Tenzin	Forest Ranger II	PWS	Crew Leader
Kinzang Chophel	Ass. Forester	PWS	Crew member
Raj Kumar Gurung	Forester	PWS	Crew Member
Pema Dorji	Sr. Forester	PWS	Crew Member
Karma Chedup	Forest Ranger II	PWS	Crew Member
Tashi Phuntsho	Forest Ranger II	PWS	Data Manager/ Crew Member
Khagayshor Guragai	Sr.Forester	PWS	Crew member
Tshering Dorji	Forestry Officer	RMNP	Crew Leader
Chimi Tshewang	Sr. Forester	RMNP	Crew Member
Dew Bahadur Dahal	Forest Ranger II	RMNP	Crew Member
Karma Wangchuk	Sr. Forester	RMNP	Crew Member
Chundu Dorji	Sr. Forester	RMNP	Crew Member
Jampel Lhendup	Forest Ranger II	RMNP	Data Manager/Crew Member
Phurpa	Forestry Officer	Samdrup Jongkhar FD	Crew Leader
Chimi Rinzin	Forest Ranger II	Samdrup Jongkhar FD	Crew Member
Karman Subba	Forest Ranger II	Samdrup Jongkhar FD	Crew Member
Dhendup Tshering	Sr. Forester	Samdrup Jongkhar FD	Crew Member
Leki Dorji	Sr. Forester	Samdrup Jongkhar FD	Crew Member
Tilak Bhandari	FR II	Samtse FD	Crew Leader
Tenzin Dorji	FR II	Samtse FD	Crew Member
Mindu	Sr. Fr.	Samtse FD	Crew Member

Tashi Dorji	Sr. Fr.	Samtse FD	Crew Member
Lha Tshering Lepcha	FR II	Samtse FD	Crew Member
Dago Dorji	Forest Ranger I	Sarpang FD	Crew Leader
Chencho Nidup	Forest Ranger I	Sarpang FD	Crew Member
Sangay Wangchuk	Forest Ranger II	Sarpang FD	Crew Member
Tshering	Sr. Forester	Sarpang FD	Crew Member
Lungten Dorji	Sr. Forester	Sarpang FD	Crew Member
Rinchen Khandu	Sr. Forest Ranger III	SWS	Crew Leader
Sangay Chophel	Forest Ranger I	SWS	Crew Member
Jamtsho	Sr. Forester	SWS	Crew Member
Tenzin Nima	Sr. Forester	SWS	Crew Member
Jambay Dhendup	Sr. Forest Ranger II	SWS	Crew Member
Chimi	Forest Ranger I	Thimphu Division	Crew Leader
Chengala	Sr. Forester	Thimphu Division	Crew Member
Sonam Wangpo	Sr. Forester	Thimphu Division	Crew Member
Kezang Phuntsho	Sr. Forester	Thimphu Division	Crew Member
Dorji Wangchuk	Sr. Forester	Thimphu Division	Crew Member
Ugyen Phuntsho	Sr. Forest Ranger III	Trashigang FD	Crew Leader
Sonam Dorji	Forest Ranger II	Trashigang FD	Crew Member
Sangay Choki	Forest Ranger I	Trashigang FD	Crew Member
Dawa Tshering	Forest Ranger II	Trashigang FD	Crew Member
Pema Lhendup	Forest Ranger II	Trashigang FD	Crew Member
Cheten Dorji	Forest Ranger II	Tsirang FD	Crew Member
Jigme Zangpo	Sr. Forester	Tsirang FD	Crew Member
Tenzin Dorji	Forest Ranger II	Tsirang FD	Crew Member
Gyeltshen	Sr. Forester	Tsirang FD	Crew Member
Dorji Drukpa	Sr. Forester	Tsirang FD	Crew Member
Jigme Wangchuk	Sr. Forest Ranger II	UWIFoRT	Crew Leader
Rinchen Dakpa	Sr. Forest Ranger I	UWIFoRT	Crew Member
Rinchen Singye	Forest Ranger I	UWIFoRT	Crew Member
Sangay	Research Assistant II	UWIFoRT	Crew Member
Sangay Wangchuk	Sr. Forester	UWIFoRT	Crew Member
Tshewang Namgyel	Sr. Forest Ranger III	Wangdue Division	Crew Leader
Tshering Phuntsho	Forest Ranger II	Wangdue Division	Crew Member
Jigme Tshewang	Forest Ranger II	Wangdue Division	Crew Member
Sonam Penjor	Forest Ranger II	Wangdue Division	Crew Member
Tashi Phuntsho	Sr. Forester	Wangdue Division	Crew Member
Yeshey Nedup	Sr. Forest Ranger III	WCNP	Crew Leader
Choki Gyeltshen	Sr. Forester	WCNP	Crew Member
Dechen Norbu	Sr. Forester	WCNP	Crew Member
Pema Dorji	Sr. Forester	WCNP	Crew Member

Ngawang Tashi	Sr. Forester	WCNP	Crew Member
Kezang Dawa	Sr. Forest Ranger I	WCNP	Crew Leader
Phurba Dorji	Sr. Forester	WCNP	Crew Member
Chandra Kumar Gurung	Sr. Forester	WCNP	Crew Member
Karma Yeshey	Forester	WCNP	Crew Member
Tilak Bahadur Ghalley	Sr. Forester	WCNP	Crew Member
Chundgue Dorji	Forest Ranger I	Zhemgang FD	Crew Leader
Kirthi Mann Subbha	Sr. Forester	Zhemgang FD	Crew Member
Dhan Bdr Subbha	Sr. Forester	Zhemgang FD	Crew Member
Tandin	Sr. Forester	Zhemgang FD	Crew Member
Nima Dorji	Forest Ranger II	Zhemgang FD	Crew Member

4. List of Data Managers

Name	Designation	Office	Remarks
Tshering Dawa	Sr. Forest Ranger III	Bumthang FD	Data Manager
Kezang Choden	Forestry Officer	Bumthang FD	Asst Data Manager
Sonam Choidup	Sr. Forest Ranger III	BWS	Data Manager
Kencho Nidup	Sr.Forester	BWS	Asst Data Manager
San Bdr Tamang	Forest Ranger I	Dagana Forest Division	Data Manager
Binod Alley	Forest Ranger I	Dagana Forest Division	Asst Data Manager
Sangay Wangmo	Forest Ranger I	Gedu FD	Data Manager
Basant Thapa	Forest Ranger II	Gedu FD	Data Manager
Choki Lham	Sr. Forester	JDNP	Data Manager
Choden Lhamo	Sr. Forester	JDNP	Asst Data Manager
Phuntsho	Sr. Forest Ranger III	JKSNR HQ	Data Manager
Sangay Wangchuk	Forest Ranger II	JKSNR HQ	Asst Data Manager
Karma Chorten Dhendup	Forestry Officer	JSWNP	Data Manager
Tshering Wangdi	Forester	JWS	Crew Leader
Rinchen Dorji	Sr. Forest Ranger II	Mongar FD	Data Manager
Chokimo	Sr. Forester	Mongar FD	Asst Data Manager
Sherab Jamtsho	Forestry Officer	Paro FD	Data Manager
Sonam Rinzin	Forest Ranger I	Paro FD	Asst Data Manager
Rabten	Forestry Officer	Pgatshel FD	Data Manager
NimaWangdi	Forest Ranger II	Pgatshel FD	Asst Data Manager
Tenzin Rabgye	Forestry Officer	PNP	Data Manager
Pema	Sr. Forest Ranger II	PNP	Asst Data Manager
Tashi Phuntsho	Forest Ranger I	PWS	Data Manager
Khagayshor Guragai	Sr.Forester	PWS	Asst Data Manager
Jampel Lhendup	Forest Ranger II	RMNP	Data Manager
Tshewang Jaimo	Sr. Forester	RMNP	Asst Data Manager
Cheki	Sr. Forester	Samdrup Jongkhar Division	Data Manager

Choden	Forest Officer	Samdrup Jongkhar Division	Asst Data Manager
Bal Krishna Giri	Sr. FR III	Samtse FD	Data Manager
Dawa Tshering Lama	Sr. FR III	Samtse FD	Asst Data Manager
Sangay Nidup	Sr. Forest Ranger III	Sarpang FD	Data Manager
Tenzin Jamtsho	Forest Ranger II	Sarpang FD	Data Manager
Dorji	Sr. FR I	SWS	Data Manager
Pema Rinzin	Sr. FR II	SWS	Asst Data Manager
Kuenzang Lhamo	Data Manager	Thimphu Division	Data Manager
Lhaba	Asst Data Manager	Thimphu Division	Asst Data Manager
Phuntsho Wangdi	Sr. Forest Ranger II	Trashigang FD	Data Manager
Karma Jamtsho	Forest Ranger II	Trashigang FD	Data Manager
Kinley Wangmo	Sr. Forest Ranger II	Tsirang FD	Data Manager
Pema Choden	Sr. Forest Ranger II	Tsirang FD	Asst Data Manager
Damber Mani Rai	Sr. Forestry Officer	Wangdue Division	Data Manager
Tshering Choden	Forestry Officer	Wangdue Division	Asst Data Manager
Prakash Rai	Forestry Officer	WCNP	Data Manager
Sonam Wangmo	Sr. Forester	WCNP	Asst Data Manager
Rinzin Tshomo	Forest Ranger I	Zhemgang FD	Data Manager
Sangay Wangmo	Forest Ranger II	Zhemgang FD	Data Manager

5. List of QAQC Team

SN	Name	Designation	Office	Remarks
		QAQC General Team		
1	Dorji Wangdi	Dy. Chief Forestry Officer	FRMD	Team Leader
2	Kinley Dem	Dy. Chief Forestry Officer	FRMD	
3	Nim Dorji	Driver	WMD	
4	Dawa Zangpo	Dy. Chief Forestry Officer	FRMD	October 2021- May 2022
5	Tashi Norbu Waiba	Dy. Chief Forestry Officer	FRMD	October- November 2021
6	Namgay Bidha	FRII	FRMD	December 2022
		QAQC Team 1		
1	Tshedhar	Sr. FR	FRMD	Team Leader
2	Pema Tenzin	Field man	FRMD	
3	Choki Dorji	Field man	FRMD	
4	Pema Tharchen	Field man	FRMD	
5	Jamphel Lhendup	Driver	NCD	August 2021-May 2022
6	Lhab Tshering	Sr. Forestry Officer	FRMD	QAQC
7	Choney Wangmo	FR II	FRMD	August 2021
8	Karma Wangdi	Driver	FPED	May-June 2022

QAQC Team 2				
1	Norbu Wangchuk	Sr. Forester	FRMD	Team Leader
2	Sangay Tshering	Field man	FRMD	
3	Tshering Samdrup	Field man	FRMD	
4	Jamtsho Cheda	Driver	FRMD	
5	Ugyen Tshering	Sr. FR	FRMD	
6	Lobzang	Sr. FR	FRMD	May-June 2022

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