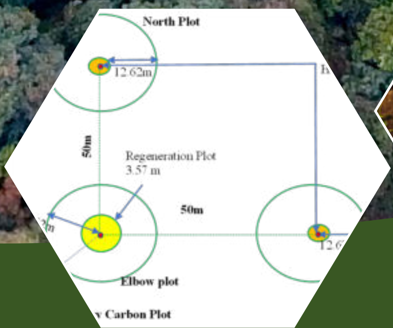
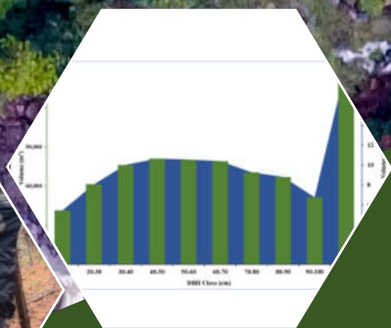
NATIONAL FOREST INVENTORY

VOLUME I







STATE OF FOREST REPORT

June, 2023

Forest Monitoring and Information Division
Department of Forests and Park Services

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NATIONAL FOREST INVENTORY

VOLUME I: *STATE OF FOREST REPORT*

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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

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FOREWARD

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 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.

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 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 express our gratitude 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 Gyeltshen, 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.

It is only because of the support of the UWIFoRT that the NFI is able to estimate forest increment and growth. The team in the tree laboratory including Mr. Dorji Dukpa, Mr. Chungdu Tshering, and Mr. Dhan Bdr Gurung showed great hard work and determination in the measurement of more than 4100 tree cores.

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) Dr. Kaka Tshering, Specialist Head, UWIFoRT; (ii) Mr. Sonam Tobgay, CFO, FRPMD; (iii) Mr. Rinzin Dorji, CFO, JDNP; (iv) Ms. Sonam Peldon, Principal Forestry Officer, FRPMD; (v)Ms. Kesang D. Tshering, Principal Forestry Officer, FRPMD; and (v) Dr. Sangay, Principal Forestry Officer, UWIFoRT, for providing your valuable comments and proof reading the final draft of the document.

Lastly, we would like to thank Mr. Arun Rai, Principal Forestry Officer in helping us with modeling and development of species occupancy maps for selected wildlife species, and to the 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

The sustainable management, utilization and conservation of forest requires a good understanding of the extent, type, use and management of the forest. National Forest Inventory (NFI) collates and provides comprehensive information for a better understanding of our forest resources. Bhutan’s forest is recognized and valued for diverse ecosystem services which provide productive (wood, carbon sequestration and storage), protective (soil and water protection) and social (recreation, aesthetic) functions. While there is an increasing demand for timber and other wood produces, our forest is subject to range of challenges including climate change, pest and disease infestation, and forest fire, etc. Ensuring sustainable forest resources requires knowledge of forest area, the growing stock and the changes and growth of forest over the years. Therefore, NFI is of a great importance for monitoring extent of forest area, timber resources, forest health, forest management, carbon sequestration, etc., which are integral components of informed decision making and supporting international, regional and national policy making.

The 2nd NFI is a part of periodic exercise to monitor the changes in the state of forest resources of Bhutan, wherein, one of the main objectives is to ensure the constitutional mandate of maintaining 60% forest cover all times. The field work for 2nd NFI started in July 2021 with prior capacity building of crews, procurement of field gears and inventory equipment. Field crews collected data from 1,969 cluster plot (CP) out of the total 2,424 CP and completed the fieldwork in June 2022.

The data collected were analyzed using rigorous statistical methods and results are presented in two volumes, i) National Forest Inventory Volume I: State of Forest Report; and, ii) National Forest Inventory Volume II: State of Forest Carbon Report. Volume I provide estimates of extent of forest area, stem density, basal area, growing stock, diversity, regeneration, forest disturbances, overview of the presence absence of important non-wood forest product species and distribution of the selected wildlife. The estimates are reported at National level, Dzongkhag level, Forest Type level, Elevation range, DBH class, Height class, and by Species.

The key finding and results are described below:

Forest Cover

- The total Forest area is estimated to be 69.71% (2.68 million ha) of the total land area while 30.29 % (1.16 million ha) of the total land area is estimated to be Non-Forest area.
- The forest area has decreased from 71% in 2016 to 69.71% in 2022.
- Sixty-four percent (1.707.572.07 ha) of total forest is categorized into very dense forest, 14 % is dense forest (368,842.87 ha), 16% is moderately dense forest (421,795.56 ha) and 7% is open forest (178,334.92 ha).
- Wangdue Phodrang has the greatest area under forest cover (258,969.43 ha), followed by Zhemgang Dzongkhag (223,067.45 ha) while Tsirang Dzongkhag has the smallest area under forest cover (54,380.94 ha).

- Broadleaved Forest constitute 67.99 % (1,819,649.63 ha) of the total forests while Coniferous Forest constitute 32.01 % (856,895.79 ha) of the forest area.
- Cool Broadleaved Forest is the most dominant forest type accounting to 754,205.57 ha (28.18 %) while Spruce Forest has the smallest forest area of 42,237.62 ha (1.52%).

Stem Density

- A total of 83,306 trees were recorded during NFI. 80,270 trees are in Forest and 3037 trees are in Non-Forest.
- A total of 1,008,117,141 trees and 523,201,912 saplings are estimated to be found in Bhutan's forest with tree density of 377 trees ha^{-1} and sapling density of 195 saplings ha^{-1}.
- Tree density has increased from 280 trees ha^{-1} in 2016 to 377 trees ha^{-1} in 2022.
- The estimated tree density is greatest in Pemagatshel Dzongkhag (490 trees ha^{-1}) and smallest in Samtse Dzongkhag (263 trees ha^{-1}).
- The estimated sapling density is greatest in Gasa Dzongkhag (551 saplings ha^{-1}) and smallest in Thimphu Dzongkhag (62 saplings ha^{-1}).
- Wangdue Phodrang Dzongkhag has greatest number of estimated total trees (101 million trees) and saplings (53 million saplings).
- Gasa and Tsirang Dzongkhags has a smallest number of estimated total trees with 20 million trees each and estimated total number of saplings is smallest in Thimphu Dzongkhag (5 million saplings).
- The total estimated trees in the Broadleaved Forest are twice (687,617,516 trees) as much as in the Coniferous Forest (320, 209,131 trees) with tree density of 378 trees ha^{-1} and 374 trees ha^{-1} respectively.
- The total saplings in the Broadleaved Forest are estimated to be 326,762,297 (180 saplings ha^{-1}) which is more than the total saplings in the Coniferous Forest with 200,177,245 saplings (234 saplings ha^{-1}).
- Tree density in the 10 Forest Types range from 254 to 426 trees ha^{-1}. Cool Broadleaved (31%) and Warm Broadleaved (25%) Forest constitutes 56% of total trees in the Forest.
- Sapling density in 10 forest types range from 161 to 350 sapling ha^{-1}. Cool Broadleaved (26%) and Warm Broadleaved (22%) Forest constitute 48% of total saplings in the Forest.
- A total tree count is greatest in the elevation range of 2000-3000 *m.a.s.l* with 357,237,185 trees (421 tree ha^{-1}) and smallest in the elevation range >= 4000 *m.a.s.l* with 18,429,498 trees (233 trees ha^{-1}).
- Total sapling count is greatest in elevation range of 2000-3000 *m.a.s.l* with 162 million sapling and smallest in the elevation range >= 4000 *m.a.s.l* with 20 saplings.
- The sapling density is greatest in the elevation range >= 4000 *m.a.s.l* with 273 saplings ha^{-1} and smallest in the elevation range <= 1000 *m.a.s.l* with 159 saplings ha^{-1}.
- The density is greatest in the smallest DBH class of 10-20 cm (191 trees ha^{-1}) and 20-30 cm (80 trees ha^{-1}), which together constitute 72% of total tree density in the forest.

- The lowest tree density is recorded in DBH class 90-100 cm with 3 trees ha^{-1}
- The density is greatest in the height class of 5-10 m (127 trees ha^{-1}) and 10-15 m (127 trees ha^{-1}), which together constitute more than two third of total tree density in the forest.
- The smallest tree density is recorded in height class >=40 m with 1 tree ha^{-1}
- *Rhododendron* spp. is estimated to have greatest number of total tree count with about 126 million trees followed by *Quercus* spp. with 81 million trees.

Basal Area

- Forest recorded an estimated average basal area of 32.74 m^2 ha^{-1} and total basal area of 88 million m^2.
- The greatest average basal area is estimated to be in Bumthang Dzongkhag (41.57 m^2 ha^{-1}) and smallest in the Pemagatshel Dzongkhag (23.43 m^2 ha^{-1})
- The total basal area is greatest in Wangdue Phodrang Dzongkhag (9.11 million m^2) and smallest in Gasa Dzongkhag (1.75 million m^2).
- The average basal area in the Coniferous Forest (34.46 m^2 ha^{-1}) is greater than average basal area in Broadleaved Forest (32.02 m^2 ha^{-1}). However, total basal area in Coniferous Forest (30 million m^2) is smaller than total basal area in Broadleaved Forest (58 million m^2).
- Hemlock Forest has the greatest basal area per ha (46.51 m^2 ha^{-1}) while the Cool Broadleaved Forest has the smallest basal area per ha (15.14 m^2 ha^{-1}).
- Basal area per ha is greatest in DBH class of =>100, with 5.13 m^2 of the total basal area per ha. Tree with DBH class 10-20 and 20-30 have a total basal area per ha of 6.87 representing 21 % of the total basal area per ha of Bhutan's Forest.
- The smallest basal area is estimated in the Height Class below 5 m which increases gradually till it reaches the peak at the Height Class of 15-20 m. The basal area density of 0.28 m^2 ha^{-1} and total basal area of 0.76 million m^2 was recorded below 5 m Height Class while the Height Class of 15-20 m Height Class recorded a basal area density of 7.13 m^2 ha^{-1} and a total basal area of 19.1 million m^2.
- Fir (*Abies densa*) has the greatest basal area (12.96 million m^2) which represents 14.78 % of the total basal area followed by oak species (*Quercus spp.)* which represents 13.04 % of the total basal area with a basal area of 11.43 million m^2.

Growing Stock

- The total growing stock of Forest is 759 million m^3 with a mean volume of 283.65 m^3 ha^{-1}.
- The growing stock per unit area is greatest in Bumthang Dzongkhag (378.63 m^3 ha^{-1}) and smallest in Pemagatshel Dzongkhag (165.07 m^3 ha^{-1}).
- Tsirang Dzongkhag has smallest growing stock of 1.26 million m^3 and contributes 1.34% to the total growing stock compared to Wangdue Phodrang Dzongkhag which has greatest growing stock of 7.73 million m^3 and contributes 10.10% to the total growing stock.

- Coniferous forest has greater volume per ha (308.54 m^3 ha^1) compared to Broadleaved Forest (273.27 m^3 ha^{-1}). On the contrary, the total growing stock of Broadleaved Forest (497,257,910.57 m^3) is 88% higher than the total growing stock of Coniferous Forest (264,388,045.88 m^3)
- Hemlock Forest has the greatest growing stock per ha (442.7 m^3 ha^{-1}) and Juniper Rhododendron Forest has the smallest growing stock (101.04 m^3 ha^{-1}).
- The total growing stock is smallest in Juniper Rhododendron Forest with 7.04 million m^3 of standing volume while the greatest total growing stock is recorded in Cool Broadleaved Forest (285.94 million m^3).
- The greatest volume per ha of 372.46 m^3 ha^{-1} is estimated at the elevation class of 2000-3000 *m.a.s.l* and lowest above the elevation range 4000 *m.a.s.l* with 70.27 m^3 ha^{-1}.
- Volume per ha is greater in the larger DBH class. The DBH Class 10-20 cm has the smallest volume per ha (15.49 m^3ha^{-1}) and the DBH Class 40-50 cm has the greatest volume per ha (30.24 m^3ha^{-1}).
- Three height classes of 15-20 m, 20-25 m and 25 -30 m constitute about 60 % of the total growing stock and tree with height less than 5m contribute only about 1.6 million m^3 of volume to growing stock which is less than 1% of the total growing stock.
- Fir (*Abies densa)* has the greatest total volume with 126.36 million m^3 standing volume closely followed Oak (*Quercus spp.*) with total volume of 115.63 million m^3. These two species constitute more than 30% total forest growing stock.

Basal Area Increment

- The periodic annual basal area increment (BAI) is 0.46 m^2 ha^{-1} yr^{-1} in Forest and 0.16 m^2 ha^{-1} yr^{-1} in Non-Forest.
- The total annual BAI in last five years in forest is 1.22 million m^2 for the entire forest.
- The BAI is greatest in the Pemagatshel Dzongkhag with 1.03 m^2 ha^{-1} yr^{-1} and smallest in the Lhuentse Dzongkhag at 0.18 m^2 ha^{-1} yr^{-1}.
- Broadleaved Forest has greater BAI per ha (0.48 m^2 ha^{-1} yr^{-1}) compared to Coniferous Forest (0.40 m^2 ha^{-1} yr^{-1}).
- The total BAI in Broadleaved and Coniferous Forest is 0.875 million m^2 yr^{-1} and 0.340 m^2 yr^{-1} respectively.
- Blue Pine Forest have the greatest BAI at 0.68 m^2 ha^{-1} yr^{-1} while Juniper Rhododendron Forest has the smallest BAI of 0.14 m^2 ha^{-1} yr^1.
- BAI shows inverse relationship with elevation. The BAI is estimated to be greatest in the elevation range <=1000 *m.a.s.l* with 0.53 m^2 ha^{-1} yr^1 and smallest in the elevation range >=4000 *m.a.s.l* with 0.09 m^2 ha^{-1} yr^1.
- Highest periodic BAI is recorded in Quercus spp. (0.007 m^2 ha^{-1} yr^1) followed by *Abies densa* (0.006 m^2 ha-1yr-1) and *Rhododendron* spp. (0.006 m^2 ha^{-1} yr^1).

Species Diversity

- The NFI recorded a total of 710 species in Bhutan. Forest recorded 701 out of the total species recorded while 208 species was recorded in Non-Forest.
- The Shannon index (H) value and and a Pielou's evenness (*J*) value of Forests is 1.75 and 0.74 respectively.
- The beta diversity in terms of Sorenson index of dissimilarity index (βs = 0.98) and Whittaker's species turn over (βw = 81) are greater in Non-Forest than in the Forest (βs = 0.93, βw = 65) which indicates the spread and uniqueness of communities.
- Zhemgang (S= 357, H=2.21, *J*=0.82) and Tsirang (H=2.19, *J*=0.82) Dzongkhags are more diverse and evenly distributed than other Dzongkhags. Gasa and Paro have lowest diversity with a H index of 1.06 and 1.07 respectively.
- Broadleaved Forest (S= 678, H= 2.01, *J*= 0.79) is more diverse and evenly distributed than Coniferous Forest (S= 192, H= 1.10, *J*=0.64)
- Subtropical Forest is more diverse and evenly distributed among the forest types with an H of 2.2 and an *J* value of 0.90. Chir Pine Forest on the other hand is least diverse with an H value of 0.58 and *J* value of 0.46.
- The species richness is highest in the elevation range 1000-2000 (525) and lowest in the elevation range >=4000 *m.a.s.l.*
- The Elevation range =<1000 *m.a.s.l* has the highest H and *J* value of 2.15 and 0.81 respectively indicating a higher diversity and more even distribution compared to other elevation ranges.

Forest Health and Disturbance

- Evidences of forest disturbances are widespread and recorded in many CP:
  - ✓ Pest and disease infestation in 334 CPs, 80% of infestation is constituted by mistletoe;
  - ✓ Timber harvesting in 330 CPs, 95% of harvesting from selective felling;
  - ✓ Grazing in 568 CPs, 14% of grazing is severe;
  - ✓ Waste/garbage in 227 CPs, 49% is constituted by pet bottles; and
  - ✓ Fire in 61 CPs, 19% of heavy fire and 57% moderate fire.

Non-Wood Forest Products

- NFI recorded 33 different species of bamboo (including four (4) species identified at genus level) and 12 of 13 genera of bamboos found in Bhutan.
- NFI also recorded six (6) species of canes. *Plectomia himalayana* is the most recorded species of cane in Bhutan.

Non-Forest Land

- 30.29 % (1.16 million ha) of the total land area is estimated to be Non-Forest area.

- A total of 26,700,949 trees and 88,113,132 saplings are estimated in Non-Forest with tree density of 23 tree ha^{-1} and sapling density of 76 saplings ha^{-1}.
- Non-Forest area recorded an estimated average basal area of 1.59 m^2 ha^{-1} in Non-Forest with total basal area of 4 million m^2.
- In addition, Non-Forest land contribute13.7 million m^3 to the growing stock of the country with mean volume of 11.78 m^3 ha^{-1}.
- The periodic annual basal increment in Non-Forest is 0.16 m^2 ha^{-1} yr^{-1}.
- Non-Forest saw 208 of the total species out of the total species recorded in Bhutan.
- Non-Forest is less diverse and evenly distributed than the Forest with an H value of 0.61 and a *J* value 0.65.
- The beta diversity in terms of Sorenson index of dissimilarity index (βs = 0.98) and Whittaker's species turn over (βw = 81) are greater in Non-Forest than in the Forest.

ACRONYMS AND ABBREVIATIONS

AUC	Area under ROC curve
BAI	Basal Area Increment
BC	Biological Corridor
BPFr	Blue Pine Forest
CBFr	Cool Broadleaved Forest
cm	Centimeter
CP	Cluster Plot
CPFr	Chir Pine Forest
DBH	Diameter at Breast Height
DoA	Department of Agriculture
DoFPS	Department of Forests and Park Services
E	East
EOFr	Evergreen Oak Forest
FIFr	Fir Forest
FRMD	Forest Resources Management Division
FRMD	Forest Resources Management Division
GI	Galvanized Iron
GoI	Government of India
GPS	Global Positioning System
H	Shannon index
ha	Hectare
HMFr	Hemlock Forest
HQ	Headquarters
IA	Inaccessible Plots
J	Pielou's evenness
JRFr	Juniper Rhododendron Forest
JUSc	Juniper Rhododendron Scrub
km	Kilometer
L	Elbow
m	million
m.a.s.l	metre above sea level
MSL	Mean above sea level
m^2	square meter
N	North
NFI	National Forest Inventory
NFI	National Forest Inventory
NFP	National Forest Policy
NLCS	National Land Commission Secretariat
No.	numbers
NRDCL	Natural Resources Development Corporation Limited

NW	North Western
NWFP	Non-wood Forest Produce
PA	Protected Area
PIS	Pre-Investment Survey
QAQC	Quality Assurance and Quality Control
ROC	Receiver operating characteristic
RS	Remote Sensing
S	Species richness
SDM	Species distribution modelling
SPAL	Soil and Plant Analytical Laboratory
SPFr	Spruce Forest
SRF	State Reserved Forest
STFr	Subtropical Forest
UWIFoRT	Ugyen Wangchuck Institute of Forest Research and Training and Research
WBFr	Warm Broadleaved Forest
βs	Sorenson index of dissimilarity
βw	Whittaker's species turn over

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1 INTRODUCTION

1.1 Background

National Forest Inventory (NFI) is the systematic collection of data and information for assessment or analysis of forest resources at the National level. The objective of NFI is to provide comprehensive information about the state and dynamics of Forests Resources for strategic and management planning as it provides trends and condition of Forest Resources over a period of time. Historically, Bhutan conserved high percentage of land area under forest cover and periodically monitored changes through the land cover assessment or mapping in 1995, 2010 and 2016 using remote sensing technologies. However, these efforts did not provide the quantitative parameters of forestry and information necessary for the sustainable management of forests. At the same time, the Forest statistics, provided through the Pre-Investment Survey (PIS) needed to be updated to be more inclusive in its objective and to monitor growth and change. The field work for the PIS was completed in 1979 and primarily focused on assessment of wood resources.

Therefore, forest inventories are planned to provide up-to-date survey of the location, composition, and distribution of the Forest Resource and their relative distribution over a given area. The data collected through these inventories provides valuable information for evaluating the forest resources, facilitating management decision making at various levels including National, Dzongkhag, or any other Management level. The main objectives of NFI are to:

- Monitor forest resources and changes therein at the National, District and Forest type levels;
- Generate information on Forest cover in different canopy density classes;
- Provide updated information on including growing stock, forest carbon, etc; and
- Provide information for national and international reporting.

The demand for improved and transparent information on forest resources is growing due to the recognition of forest as cost-effective and nature-based solution to combat climate change. Therefore, NFI is important for Bhutan to monitor forest change and in ensuring fulfillment of the Constitutional mandate of maintaining 60% of the land area under forest cover at all times. Furthermore, the National Forest Policy of Bhutan 2011 has emphasized the importance of conducting periodic assessment of forest resources. Accordingly, the 1st NFI was conducted between 2012-2015.

Bhutan embarked upon the 2nd NFI in 2021 with the initiation of field work in July 2021. The field work was completed in June 2022. Data was collected from 1,969 cluster plot out of the total 2,424 cluster plots (CP) spread across the country. Additionally, the understorey above-ground biomass carbon data and soil organic carbon data was collected from 354 CP, and Quality Assurance and Quality Control (QAQC) was conducted in 258 CP over one year. The data cleansing, analysis and report preparation was completed during July 2022- June 2023.

In addition to field data collected, inaccessible/non-response plots were accounted for the estimation of forest area by overlaying the Forest Type Map of Bhutan 2022 and Land Use and Land Cover Map 2016 on QGIS software, and, validated using high resolution google earth imageries, Open Foris Collect Earth and, in consultation with the field offices.

1.2 Scope

The NFI not only provides estimates of forest growing stock, biomass, carbon stock and forest increment but also offers additional information on ecological condition and distribution of species. The estimates generated from analysis of the data will be consolidated and 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 first part of the NFI report; the National Forest Inventory Volume I: State of Forest Report and shall hereafter be referred to as the report. The report provides estimates of traditional forest parameters such as the forest area, tree count, basal area, growing stock, along with estimates on increment, regeneration, species diversity, forest health and disturbance and Non-wood Forest Produce (NWFP). The estimates are further reported for different categories:

i. National level
ii. Dzongkhag level
iii. Forest Type
iv. Elevation
v. Diameter Class
vi. Height Class
vii. Species

The report shall provide estimates of the various forest parameters collected during the 2nd NFI and discuss the results independently; and in comparison, to the results of the first NFI. This shall provide updated information for planning and policy formulation in forest management; and assist in striving to the achievement of the long-term plans of the Royal Government of Bhutan.

1.3 Forest Resources Assessment in Bhutan

1.3.1 Background

Bhutanese people have lived in harmony with nature and forest for centuries as is evident from the longstanding culture and oral traditions passed along the generations. The scientific management was initiated in 1952 with the establishment of the Department of Forest. The Department ventured in sustainable forest management through the establishment of the Working Plan Division and declaration of Game Sanctuary in the 1970s (DoFPS, 2021a). Experts from Sweden, Japan and India were invited to assess the potential of forest over a decade (1961-1970) (GoI, 1976 (a)). The experts emphasized the need for a detailed survey of Forest Resources in Bhutan. Further, the National Economic Policy of Bhutan provided the much-needed edge to carry out a national wide assessment of forests; the Pre-Investment Survey of Bhutan. The economic policy contemplated a growth rate of 10 % per annum in the revenue generation from Forests and accordingly, the National Forest Policy (NFP), 1974 was passed wherein, objective 3, Part II of the NFP 1974 emphasized on a need for a comprehensive resources survey and the preparation of scientific forest working plans for "*operation and utilization of forest wealth*". Subsequently, the PIS survey was conducted (1974-1981) followed by two National Forest Inventories and three Land cover assessments on the National level. A brief account of major forest resources assessment is discussed hereafter.

1.3.2 Pre-Investment Survey

1.3.2.1 Background

The first national field-based forest assessment, referred to as the Pre-Investment Survey (PIS) was carried out from 1974 to 1981 with the support of the Government of India (GoI). The PIS was mainly focused on timber assessment in *specified areas* for establishing wood-based industries in the country. It provided the first estimate of forest cover as well as growing stock in the country. Since then, several remote sensing exercises were carried out which monitored the changes in forest cover over time. These sections provide a brief description of the PIS, summarized and reproduced from the PIS Reports (GoI, 1976a, 1976b, 1980b, 1980a, 1981).

The PIS survey was undertaken in four phases (Phase I to IV) over a period of 5 years and covered a total of 29,136.4 km^2 in comparison to the planned area of 31,602.01 Km^2. Area estimation were done using aerial photographs from 1956-1958 (Phase I- III) and 1977-1978 (Phase IV) while volume estimates were generated using volume equations developed during the data collection for the PIS. Forest areas were classified using Champion and Seth's classification. An abstract of the of the PIS survey is shown in Table 1.1.

Table 1.1 Summary of the PIS Survey

Phase	Region	Area surveyed	Block	Cluster	Sample plots			Remarks
					Total	Enume-rated	IA*	
I	North western	7,920.21	236	917	1,832	824	292	Remaining points were in cultivation land and in habitation
II & III	Central and Eastern	10,897.91	-	-	2,458	1,401	429	Plots in the vicinity of the forest and falling in cultivated land and human habitat were visited to look for changes.
IV	South	10,318.28	-	1,132	2,264	1,224	396	

**IA = Inaccessible plots*

Figure 1.1 shows the designation of area for the different Phase of survey under the PIS.

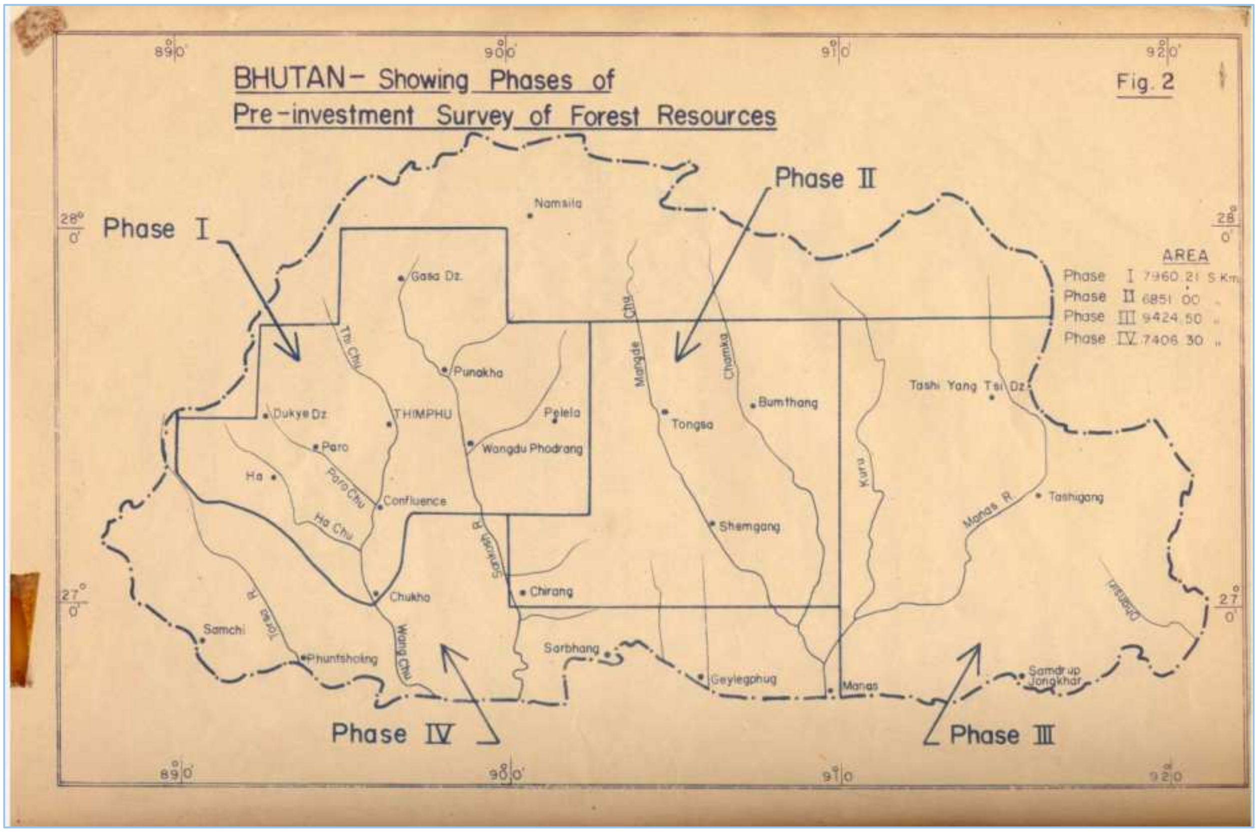


*Figure 1.1 Phases of the PIS (***reproduced from** (GoI, 1976a)**)**

1.3.2.2 Fieldwork

Phase I: North Western Bhutan

236 blocks were systematically laid out at 6 km x 6 km over the survey area falling along the catchment of Toorsa, Ha, Paro, Sunkosh and parts of Mangde chu. Each block consisted of four (4) sampling clusters where each cluster has two sample points each situated 100 metres from the cluster centre. A total of 1,832 sample points were identified in the North Western (NW) region from which data were collected from 45 % of the total sample points identified. The rest was inaccessible or located in human habitation or cultivation areas. From the total of 787 aerial photographs used, 70.6 % of the area was estimated to be forest and 29.4 % was non-forest. The forest area was predominated by upland hardwood and lowland hardwood (28.2 %) followed closely by Fir & Spruce Forest (22.8 %). The total growing stock for the NW region was estimated at 131.37 million m^3.

Phase II & III: Central and Eastern Bhutan

The Phase II & III of the PIS was built on the experience and lessons learned from the Phase I. Phase II started on 6th February 1976 and was completed in April 1977 while the field work for Phase III was conducted from 10th May 1977 to February 1978. The sampling design was modified to have a better reach in the area and the survey was designed to include more variables and for better accuracy. Two-point single cluster sampling, at a spacing of 3 km x 3 km was adopted; with two sample points for each cluster and located at 100 m from the cluster centre, in the North-South direction. Data collection was done from 1,401 sample points (57 %) from the total 2458 sample points. 17.5 % of the total sample points were inaccessible while the survey team physically monitored 25.5 % of the plots falling in cultivated land, human habitation and in vicinity of the forests. A forest area of 83.3% was estimated based on 787 aerial photographs of 1956-58. However, the possibility of a decline in the actual forest cover was indicated as a result of shifting cultivation over the years. Further, the PIS report also emphasized that the "*forest area includes blanks, alpine pastures, scrub forests as well as degraded open forests or poor quality*". A total growing stock of 213.98 million m^3 was estimated for all forest types in the Phase II and Phase III of the PIS.

From the total of 787 aerial photographs used, 70.6 % of the area was estimated to be Forest and 29.4 % was Non-Forest areas. The Forest area was predominated by upland hardwood and lowland hardwood (28.2 %) followed closely by Fir & Spruce Forest (22.8 %). The total growing stock for the NW region was estimated at 131.37 million m^3.

Phase IV: Southern Bhutan

The sample design adopted for Phase II and Phase III was adopted for Phase IV as well and 2,264 sample points were identified for 1,132 clusters. Data collected from the 1,224 sample points (54 %) of the total sample points identified estimated a total growing stock of 183.632 million m^3.

Phases I, II and III used aerial photographs from 1956-58 for the estimation of forest area. And since a lot has changed over the two decades as a result of shifting cultivation and deforestation in the south, fresh photography was carried out during 1977 and 1978. A summary of the forest area and growing stock (GS) in all the regions is summarized in Table 1.2.

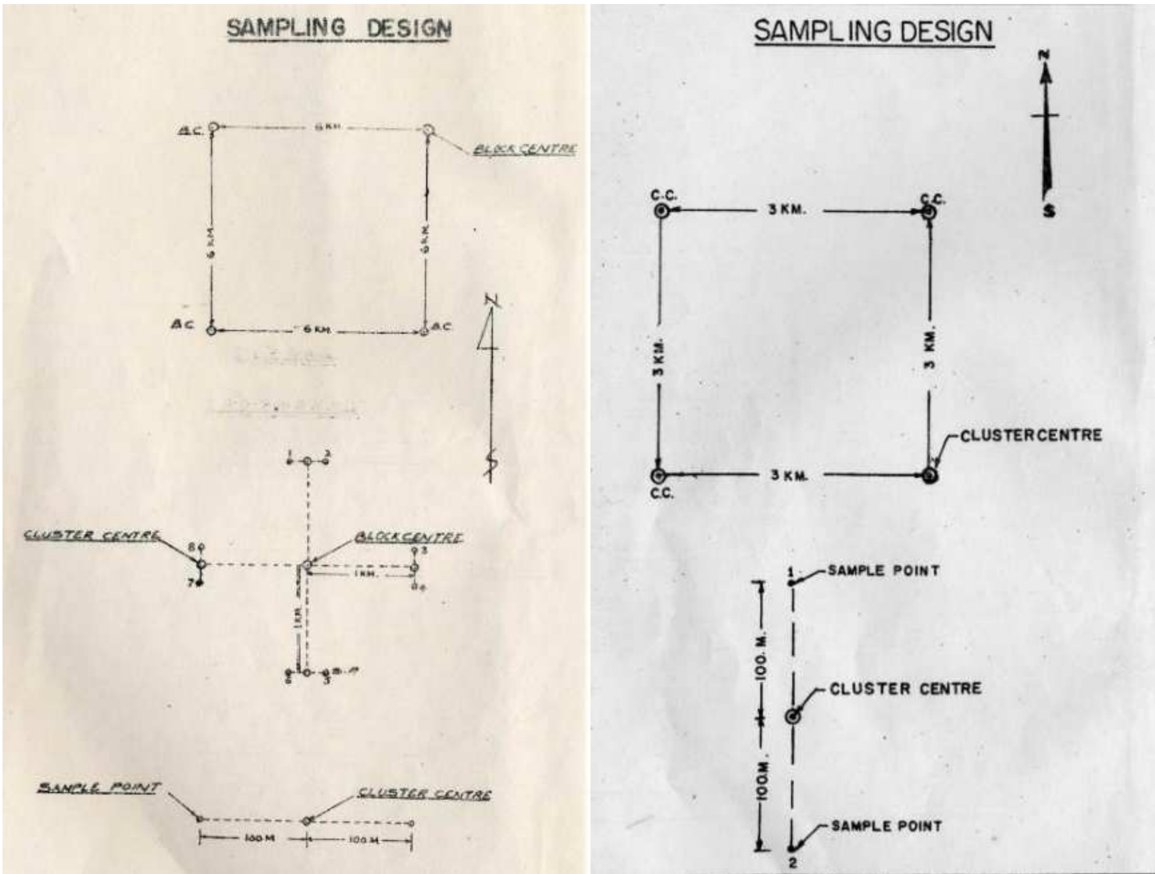


Figure 1.2 Sampling design for Phase I(left) and Phase II, III and Phase IV (right) (reproduced from GoI, 1976(II) and GoI, 1980 (II)

Table 1.2 Summary of forest area and growing stock estimated (in million (m)) in PIS

Phase	Region	Area* (m ha)	Year of Aerial photograph	Forest area (m ha)		Non-Forest (m Ha)	GS (m m^3)
				Forest	Tree cover		
I	North western	0.79	1956-58	0.56	0.5	0.23	131.37
II & III	Central and Eastern	1.09	1956-58	0.91	0.82	0.17	213.98
IV	South	1.03	1977-78	0.88	0.83	0.15	183.63
Total		2.91		2.35	2.16	0.55	528.98

**** Remaining areas (Area-(Forest+NF)) are under clouds or under gaps***

For the PIS, data collection was done from a total of 2.91 million ha and a total of 528.98 million m^3 was estimated from the surveyed area. The PIS survey estimated an overall average forest cover of 80.71 % including a tree cover of 74.11 % (Table 1.3). While the PIS defined Forest as all land which does not fall under cultivation, orchards or habitation and measured all Government Reserve Forest Land, the tree cover (TC) only accounted for the areas with tree cover. All tree species

equal to and above 5 cm DBH[1] were measured and classified under "Tree cover", Therefore, the forest area was estimated to be 2.16 million ha. Subsequently, the total growing stock of 528.98 million m^3 and growing stock per ha of 244.98 m^3ha^{-1} was estimated. However, if the total country area reported during the conduct of the PIS survey (46,600 km^2) (GoI,1976(I)) was taken into account assuming non-surveyed area represented same proportion of forest and non-forest like the surveyed area, the total forest area would have been 3.76 million ha with an estimated growing stock of 846.03 million m^3.

Table 1.3 Forest cover estimated in the PIS

Category	Area (m ha)	Area (%)	Growing Stock (GS) per ha (m^3)	Forest area prorated to country area	Estimated GS (m m^3)
Forest (incl TC)	2.35	80.71	224.93	3.76	846.03
Tree cover	2.16	74.11	244.98	3.45	846.03

The PIS of Bhutan provided information and paved the way for forest inventory at the forest management and operational level. This was subsequently followed with numerous remote sensing exercises for the assessment and study of the trends of the land cover and land use changes in Bhutan. Further, forest areas were identified for the establishment of Forest Management Areas, increasing timber supply in the market and promoting wood-based industries. Volume equations for 28 major timber species and one general equation for the rest of the species were developed during the PIS, which is still used as a basis for the estimation of volume and a reference for the development of new volume tables in Bhutan.

1.3.3 1st National Forest Inventory

1.3.3.1 Background

The PIS report guided the Department of Forests and Park Services (DoFPS) in the scientific management of forests over three decades. However, with rapid modernization and increasing pressure on forest resources, a comprehensive forest resource inventory was felt imperative. NFI in combination with Remote Sensing (RS) tools and techniques shall enable the monitoring of changes in forest cover and forest resources over time. Therefore, the Department embarked on a comprehensive resource inventory from 2009-2015 to provide quantitative baseline required for forest management in Bhutan. The NFI was conceptualized to provide a clear picture of the Forest Health, Species Composition, Biomass and Carbon, besides the traditional forest parameters (species composition, standing volume, increment, etc.).

[1] For the NFI, DBH equal to and above 5 cm and below 10 cm are considered sapling while all trees equal to above 10 cm are accounted as trees.

Accordingly, sampling design was developed through a series of technical and stakeholder consultations and piloting of the methodologies in the field. NFI sampling design consists of 2,424 cluster plots (CP) laid systematically across at 4 km x 4 km grid across the country. All plot centres were monumented with galvanized iron (GI) pipe to aid in the relocation of plots during the future NFI. Each CP consisted of 3 circular plots of 12.62 m radius placed on a "L" shaped transect at 50 m apart and referred to as the Elbow (L), North (N) and East (E) plot. Regeneration was measured in sub-plots of 3.57 m radius laid inside the "L" plot while herb plots of 0.57 m are laid in N & E plots. 20 % of the total 2,424 CP were sampled for measurement of understory shrubs, herbs, litter and soil data collection. Since NFI sample plots were permanent, the sampling design and plot design for the 1st and 2nd NFI is the same and hence, shall be explained in detail in 2.1.1 Sampling Design.

1.3.3.2 Result

The field crew enumerated a total of 1,685 cluster plots from the total of 2,424 CP and the remaining plots were inaccessible. Accordingly, data were analyzed and estimates reported for Forest and Non-Forest areas. For the NFI, Forest cover was estimated based on Forest defined in National Forest Policy 2011. Forest in Bhutan is defined as a land area with trees spanning more than 0.5 ha with trees higher than 5 m height and a canopy cover of more than 10%. Forest cover constituted approximately 71% of the total geographical area and included forested areas in the State Reserved Forest (SRF) land, private land and other institutional lands, which fulfilled the minimum thresholds of the criteria under the Forest definition (Table 1.4).

Table 1.4 Summary of the estimates from 1st NFI

Land Cover	Area (m ha)	Forest Cover (%)	Total Growing stock (million m^3)	Volume per ha (m^3)
Forest Land	2.73	71	944.26	346

The total growing stock of Bhutan's forest was estimated to be 944 million m^3 with an average growing stock of 346 m^3 per ha. Growing stock is the standing volume for all trees having a minimum DBH of 10 cm and was estimated using the 28 general volume equations developed during PIS for the NFI.

The NFI design has been developed to generate estimates for the basal area at 15% margin of error with 90% confidence interval at National and Dzongkhag level. Although the CP consists of three disjoint plots, it was treated as a single sampling unit in the analysis. For statistical purposes, the size of the NFI was expressed as the total number of 2,424 sampling units distributed across Bhutan.

1.3.4 2nd National Forest Inventory

Permanent sample plots measured during the 1st NFI was re-measured to monitor change (any disturbances, land use change, etc.) and growth (how individual trees are growing, dbh, height). Field work was envisioned, and data collection parameters and methodologies were updated based on the lessons from the 1st NFI. The data collection was decentralized to the field offices in an attempt to institutionalize the NFI into the activities of the field offices and to improve data quality. Data collection for the 2nd NFI was collected using tablets and data collection, cleansing was done using Open Foris Collect software developed by FAO. Some of the difference between the 1st and 2nd NFI are discussed in Table 1.5.

Table 1.5 Key difference between 1st and 2nd NFI

Elements	1st NFI	2nd NFI
Implementation Modality	Centralized NFI Fieldwork	Decentralized NFI Fieldwork to field offices
Data collection tool	Trimble Juno GPS	Open Foris Collect mobile with android tablet
Data transfer	Manual transfer of data	Real time upload of data in the google drive
Tree	Tree was measured and recorded	1. All individual trees are tagged 2. Further, modality for numbering and identification of unknown trees updated
Relocation of PSP	Prominent structure was identified	1. Reference structure identified and photographed 2. Witness tree tagged and recorded in SW Map
Canopy cover	10 records were taken for each plot with GRS densitometer	No. of observations increased to 25 reading per plot
QAQC	Mainly focused on Cold check	Institutionalized the QAQC system in the then Forest Resources Management Division (FRMD); conducted hot, cold and blind check for quality data collection
Capacity building	Nationwide since NFI was centralized	Training for NFI fieldwork conducted in smaller groups (11 Dzongkhags) for better reach and in line with Covid-19 protocol
Confidence Interval	Estimates are reported at 90% Confidence Interval	Estimates are reported at 95% Confidence Interval in line with the IPCC 2006 Guideline

The field work was conducted from July 2021-June 2022 amidst the uncertain times of the pandemic and erratic weather conditions. Subsequently, data collation and analysis were completed from July 2022-May 2023. The activities of the NFI can be grouped broadly into three phases:

1.3.4.1 Preparatory Phase (July 2020-June 2021)

The preparatory phase was an amalgam of activities to streamline the NFI process and make data collection easier. The process for decentralization of the NFI fieldwork was gradually planned with the update and revision of the Data Collection Protocol and the Implementation Modality for the 2nd NFI. The NFI manual was also revised incorporating necessary changes for quality data collection. It was also felt important to update the data collection tool from Trimble Juno GPS to an easier, user friendly and open-source tool. Therefore, use of Open Foris Collect and Collect Mobile for data collection and cleansing was piloted in forest management units and slowly integrated into the NFI.

Fund for fieldwork was sourced through the REDD+ Readiness Project and the Bhutan for Life Project in addition to the RGoB financing. Field crew and data managers were identified in all field offices with the Chief Forestry Officer of the concerned Field office as the principal coordinator of the NFI fieldwork, the then FRMD as the principal coordinating Division in the Headquarter (HQ); and the Head of the Department as the overall Incharge of the NFI. In anticipation of the fieldwork, capacity building programs for field data collection and data management were conducted for all crew members and data managers. The preparatory phase took place during a period characterized by pandemic induced anxiety and uncertainty. Further, the NFI Training for 27 crews was conducted over a period of 4 months following Government Protocols in Place during the COVID-19. In addition, a virtual training on Data Management was held on July 1-3, 2021 for crew leaders and data managers of all field offices.

1.3.4.2 Implementation Phase (July 2021-June 2022)

NFI fieldwork formally kickstarted on 8th July 2021 in Tsholingkhar Gewog, Tsirang Forest Division. Subsequently, fieldwork was planned and implemented by the field offices based on local conditions. A team of five crew members including the crew leader enumerated the plots, while the data managers compiled and cleansed the data in addition to submitting the carbon data to the headquarters.

1,969 CP were enumerated by the field crew in addition to a total of 20% of 2,424 NFI CP designated for collection of samples to estimate understorey and herbaceous above-ground carbon stock, litter carbon stock and soil carbon stock. Trees in these designated plots were cored to understand the growth and increment of the individual trees and forest stand. The samples were sent to the Soil and Plant Analytical Laboratory (SPAL), Department of Agriculture (DoA), Semtokha for laboratory analysis of carbon content in the soil and herbaceous plants while tree core samples were sent to the laboratory measurement at Ugyen Wangchuck Institute of Forest Research and Training (UWIFoRT).

In addition, FRMD formed three quality assurance and quality control (QAQC) teams to monitor and re-measure CP randomly selected as per the NFI manual. The QAQC team re-measured a total of 258 CP including 39 hot checks, 99 cold checks and 120 blind checks.

Hot checks are inspections conducted as part of the training process by QAQC staff to provide immediate feedback to crew about their performance, both during the training and/or during the field work on their assigned plots.
Cold checks are inspections or remeasurements of plots that have been measured by field crews by the QAQC team in absence of the original field crew but with the data collected by crews as reference.
Blind checks are the remeasurement of the plots measured by the original crew but without the presence of original crew and also without the access to copy of data collected by the original crew.

1.3.4.3 Data Analysis and Report Preparation (July 2022- June 2023)

Rigorous data cleaning and compilation was done immediately after the completion of the NFI fieldwork. Two field crew along with the data managers were invited to help in data compilation, cleansing and validation. Further, detailed data cleaning for all parameters by individual entities was done over a period of 6-7 months. In addition, data received from SPAL on the understorey and herbaceous above-ground carbon stock and litter carbon stock, and, UWIFoRT on tree ring analysis were compiled, reconciled to the tree data, and finalized for data analysis at different levels.

These data were analysed in the R statistical package version 4.0.3 and 4.2.3 and complimented through the use of Microsoft Office. The methodologies, design and results of the 2nd NFI and in comparison, with the 1st NFI shall be deliberated in detail in the chapters hereafter.

FIELD METHODOLOGY

2 METHODOLOGY

2.1 Field Methodology

2.1.1 Sampling Design

The National Inventory design was based on a systematic distribution of regular grids with each circular sampling unit located at the intersection of the grid. There were 2,424 cluster plots laid at 4 km x 4 km grids spread across the country and the centre of all NFI plots are monumented with a stainless-steel rod to establish it as a permanent sampling plot for the ease of re-measurement in the future. Each cluster plot consists of 3 circular plots of 12.62 m radius placed on a "L" shaped transect 50 m apart and referred to as the Elbow, North and East plot (Figure 2.1)

Understorey above-ground carbon samples were collected from 20% of the total cluster plots,

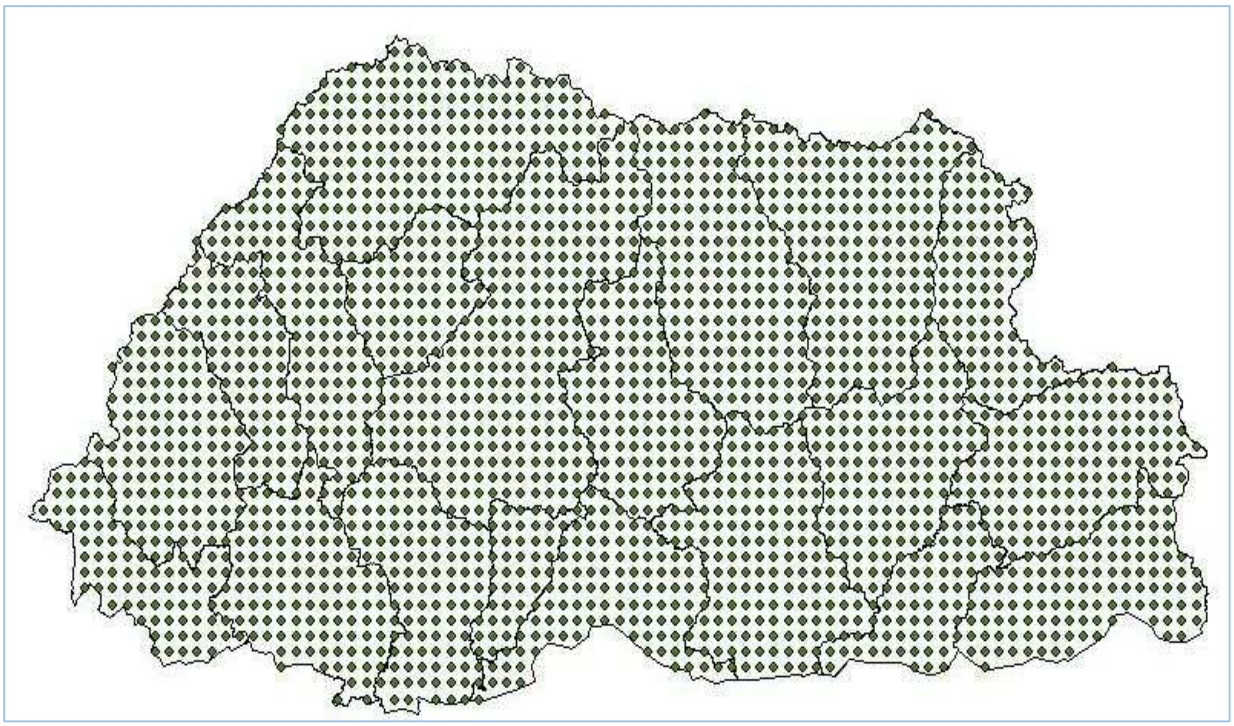


Figure 2.1 NFI Sampling Design

which were selected systematically from 2,424 cluster plots. At each identified understorey carbon plot, a 5 m x 5 m square plot was laid out 20 m away from the Elbow plot in the south west direction for destructive sampling of the shrubs. Herb samples were collected destructively from 1 m x 1 m square plot laid within the shrub plot. Similarly, litter samples were collected from 30 cm x 30 cm plot laid inside the herb plot and soil samples were collected using 10 cm x 10 cm soil sampling frame laid inside the litter sample plot up to 30 cm depth. The layout NFI plot design is described in Figure 2.2.

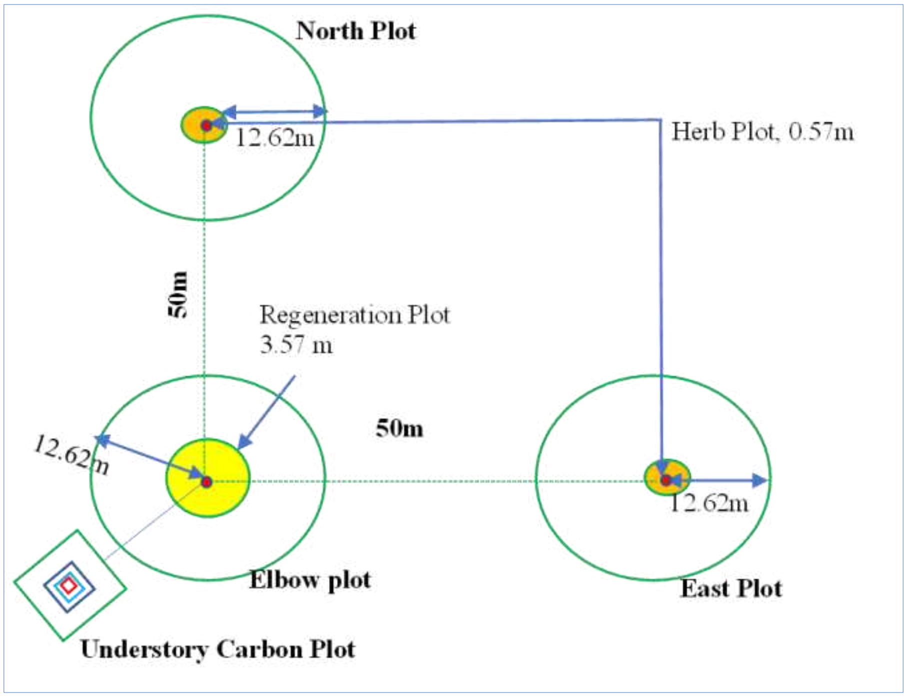


Figure 2.2 NFI Plot Design

2.1.2 Data Collection

NFI data collection was done using Open Foris Collect Mobile installed on handheld android device. Upon completion of the enumeration of each cluster plot, the data was exported and stored in a designated Google drive and SD card installed in the Android tablet. A copy of the same data was also collected in paper forms or in field notebooks to ensure information were entered correctly. The Google drive can be directly accessed by the designated data manager in the office. NFI collate data on trees, saplings, herbs, shrubs, dead woods, soil samples, mammals, reptiles and birds. Some of the generation requirements were as follows:

- The diameter of trees was measured over bark at 1.37 m from the base of the tree using diameter tape and referred to as the Diameter at Breast Height (DBH). The minimum threshold DBH is 10 cm for trees and 5 cm for saplings.
- All data for trees, saplings, shrubs, NWFPs, mammals, birds and reptiles were collected from the circular plot of 12.62 m radius.
- Regeneration data was collected from concentric smaller circular plot laid within the L plot with a 3.57 m radius.
- Herb data was collected from concentric circular 0.57 m radius sub-plots laid in the N & E Plots.
- Tree height was measured using *Haglof* Laser Geo Hypsometer for all trees within the plot boundary.
- Canopy cover and stand height, slope and aspects was measured using appropriate equipment and recorded for all cluster plots.

- Understorey shrubs and herb samples was collected using destructive sampling method, which were weighed in the field and sent to SPAL for biomass analysis.
- Soil samples was collected up to 30 cm depth in three different layers of 0-10 cm, 10-20 cm and 20-30 cm.
- Tree cores was collected from 20% of the CP which were designated as understorey carbon plots. The core sample was collected using *Haglof* increment borer; minimum core length of 15 cm for larger trees and complete core for smaller diameter trees was collected, stored in plastic straws and sent to tree laboratory, UWIFoRT for drying, examination and measurement.
- Presence and absence data of forest disturbance such as fire, pest and diseases, timber harvesting and others was collected in all plots.

2.1.3 Data Management

NFI Data received from the inventory crews were regularly updated in the Open Foris Collect database and a copy of raw data was maintained with work-station as well as in the Google drive for each crew separately. Subsequently, the data were cleaned using the preset validation rules in the collect, manual correction and re-entry of data from back up data, file by file cross validation with and exhaustive data cleansing were done including the identification of the unknown plants.

2.2 Data Analysis

2.2.1 Software Packages

The analysis of the NFI data were performed in R statistical version 4.0.3 and 4.2.3. The maps presented in the report were developed in QGIS version 3.26.2 and charts and graphs were prepared in Microsoft Office Excel (2019).

2.2.2 Results Aggregation and Reporting Unit

The estimate at the National level includes both Forest and Non-Forest areas while estimates for Forest were further reported by National, Dzongkhag and Forest Type level, Elevation, DBH and Height class.

2.2.2.1 Forest Type

Grierson & Long (1983a) classified vegetation type of Bhutan into 11 categories of Subtropical Forest (STFr), Warm Broadleaved Forest (WBFr), Chir Pine Forest (CPFr), Cool Broadleaved Forest (CBFr), Evergreen Oak Forest (EOFr), Blue Pine Forest (BPFr), Spruce Forest (SPFr), Hemlock Forest (HMFr), Fir Forest (FIFr), Juniper Rhododendron Scrub (JUSc) and Dry Alpine Scrub (DASc). This classification was loosely understood as the Forest Type of Bhutan. The vegetation in the Dry Alpine Scrub does not qualify to be classified as "Forest" as per the Forest definition adopted and has been categorized under "Shrub". On the other hand, the vegetation falling in the Juniper Rhododendron Scrub has been categorized into two classes; (i) the Juniper Rhododendron Forest (JRFr) for those fulfilling the Forest definition, and (ii) the others which did not qualify as "Forest" has been retained in Juniper Rhododendron Scrub (JUSc) as shrub land. Therefore, NFI estimates are reported for 10 Forest Types.

2.2.2.2 Elevation

NFI estimates are reported for different elevations in metres above sea level (*m.a.s.l*) which is basically the height measured from the surface of the ocean (orthometric/height above mean sea level (MSL height)). During the data collection, the altitude was recorded from the Global Positioning System (GPS) reading in addition to the auto recording of altitude on the data collection device to prevent entry of *off range* elevation. GPS measures the ellipsoid height which is then converted to orthometric/MSL height (NLCS, 2022) using the "*SOP for Extracting Geoid value and computing MSL height*" prepared by the Geodesy Section, Topographical Survey Division, National Land Commission Secretariat (NLCS).

The elevation was then classified into five categories of <1000 *m.a.s.l*, 1000-2000 *m.a.s.l*, 2000-3000 *m.a.s.l*, 3000-4000 *m.a.s.l* and >= 4000 *m.a.s.l*. This classification corresponds with the elevation range for Forest Types of Bhutan and was adopted to ensure consistency with previous studies and the first NFI of Bhutan.

2.2.2.3 DBH Class

The DBH was classified into 10 classes with class interval of 10 cm. These classes were 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-60 cm, 60-70 cm, 70-80 cm, 80-90 cm, 90-100 cm and >=100 cm. The DBH class >= 100 cm included all trees which has DBH of 100 or more.

2.2.2.4 Height Class

Tree height was classified into 9 class of <5m, 5-10 m, 10-15 m, 15 -20 m, 20-25 m, 25- 30 m, 30-35m, 35-40 m and >=40 m. The minimum height of tree recorded in the NFI is 1.5 m and the mean height of all trees was 13 m.

2.2.2.5 Species Level

NFI recorded a total of 83,306 individual trees and about 81,709 trees were identified up to species level or genus level. However, 1,597 trees could not be identified despite using all kind of technologies, experts and photographs of these plants. Collection of herbarium samples was not feasible in the field as the plots were located in faraway locations and maintaining such samples were practically impossible since the crew has to be in field for a prolonged period of time.

Since there were huge number of different species recorded, it was not practical to generate estimates for each individual species. Therefore, in consistent with the first NFI, estimates were generated for selected species which has species specific volume equations and other species were clubbed and reported as "*Other*s".

2.2.3 Descriptive Statistics and Summaries

The estimates were generated at 95% confidence interval at National level based on the Forest and Non-Forest classification. The weighted mean at cluster plot was estimated by weighing the sampling design, wherein accessible plots were allocated weight of "1" following the principles of inclusion probability and probability sampling; all trees in the sample plot are assumed to have equal probability of being sampled and proportion were used where applicable (Gregoire & Valentine, 2007; Jayaraman, 2000; Kleinn, 2013). The sample mean of the parameters is estimated using the equation (2.1).

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \tag{2.1}$$

Where,

$\bar{y}$ is the population mean of the parameter;
n is number of samples; and
y is the sample value

The per ha estimated were then estimated using equation (2.2), (2.3), (2.4)

$$\bar{y}_{ha} = \bar{y}\, x\, A_{exf} \tag{2.2}$$

$$A_{exf} = \frac{1}{A_p} \tag{2.3}$$

$$A_p = \pi r^2 \tag{2.4}$$

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 (2.5), (2.6) and (2.7) respectively. It is assumed that all forest parameters are normally distributed across the space.

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

$$SE = \frac{s}{\sqrt{n}} \quad (2.5)$$

$$CI = t * SE \quad (2.6)$$

(2.7)

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)

Further, a brief explanation of estimation methods like area estimation method, tree count estimation, basal area estimation, volume estimation, increment estimation, species diversity area is described in respective chapters for better insight.

The estimate for all reporting units is firstly aggregated at the subplot level by area of interest and the mean is computed at the CP level. CP mean is used for further aggregation by the domain of interest. The total statistics of any domain are estimated by multiplying the mean value with the estimated value. Error was converted into percentages and combined uncertainty was calculated using the error propagation method defined in equation (2.8) (IPCC, 2006).

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \cdots + U_n^2} + \quad (2.8)$$

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.

2.3 Plot Accessibility

NFI by design provides equal weight to all plots and all aggregations are based on the mean estimate at cluster plot. CP is considered as accessible even if one subplot is accessible. A total of 1,969 cluster plots were accessible. This constitutes about 81% of the 2,424 cluster plots. Other 19% of the CP could not be accessed due to difficult terrain and harsh conditions such as the steep slopes, snow glaciers in the high-altitude areas, unfavourable weather conditions and security reason along the international borders. Table 2.1 shows the percentage of accessible plots by Dzongkhag and Figure 2.3 shows the distribution of the accessible and inaccessible plots.

Table 2.1 Percent of plot accessibility by Dzongkhag

Dzongkhag	Total Plot	Accessible Plot	Inaccessible plot	Accessibility (%)
Bumthang	167	151	16	90
Chhukha	113	104	9	92
Dagana	107	107	0	100
Gasa	201	105	96	52
Haa	121	89	32	74
Lhuentse	181	78	103	43
Mongar	120	100	20	83
Paro	81	77	4	95
Pemagatshel	63	60	3	95
Punakha	70	54	16	77
Samdrup Jongkhar	119	110	9	92
Samtse	80	73	7	91
Sarpang	104	101	3	97
Thimphu	114	104	10	91
Trashigang	137	135	2	99
Trashi Yangtse	90	73	17	81
Trongsa	113	80	33	71
Tsirang	42	39	3	93
Wangdue Phodrang	251	196	55	78
Zhemgang	150	133	17	89

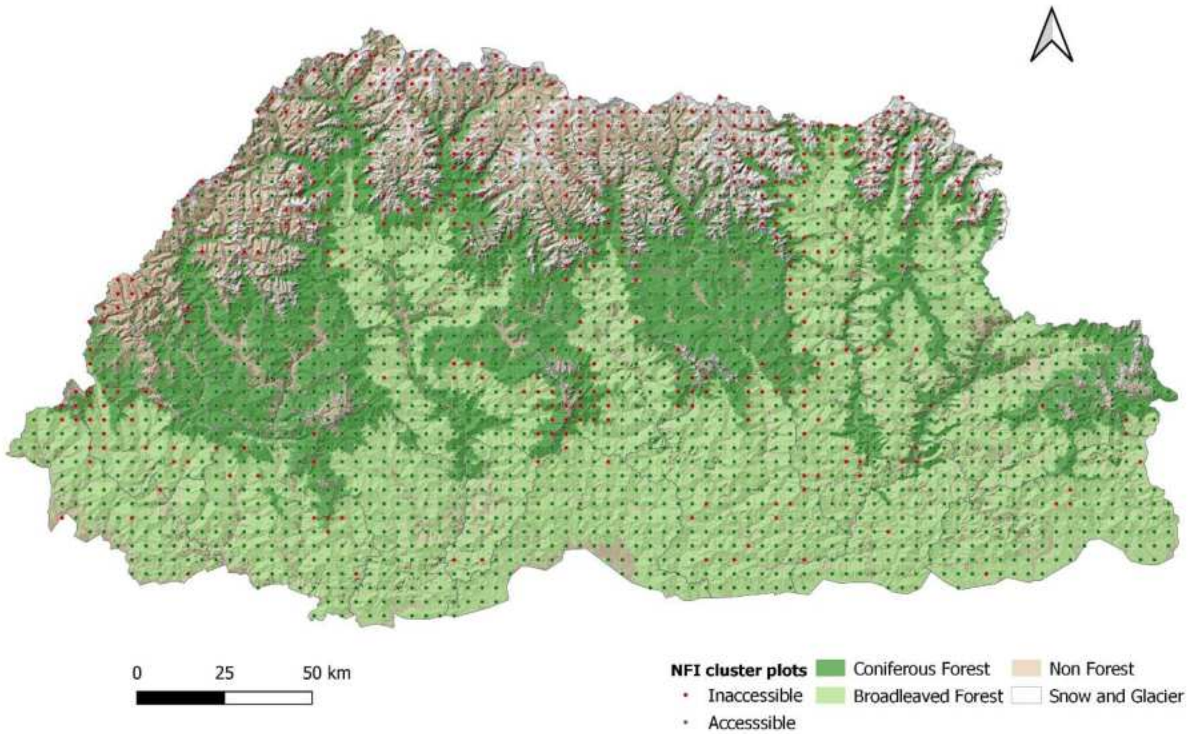


Figure 2.3 Distribution of Accessible and Inaccessible plots

One of the main recommendations from the implementation of the 1st NFI was to decentralize the implementation to the field offices. This has resulted in the increase in plot accessibility with the increase in the percentage of accessible plots by 12 % from the 1st NFI. The constitution of NFI crews from their respective working jurisdiction of the field offices has greatly helped in better planning and accessing the previously inaccessible plots. The field work could be completed in one single phase despite difficult terrain, poor accessibility, harsh weather conditions and restriction imposed by the COVID-19 pandemic.

2.4 Limitations of the Estimates

- NFI data were collected from 2,424 plots at 4 km X 4 km and estimates are generated to provide a broad picture of the growing stock and other forest parameters. NFI plots shall need to be intensified and plots generated for forest management level inventory to provide better and more accurate estimates for planning and promotion of forest based industries.
- Non-response plots were accounted for the estimation of forest area by overlaying the Forest Type Map of Bhutan 2022 and Land Use and Land Cover Map 2016 on QGIS software, and, validated using high resolution google earth imageries, Open Foris Collect Earth software and in consultation with local expert.
- Non-response plots were not accounted for other quantitative parameters to avoid the introduction of errors.

- Tree cores were collected from all accessible carbon plots. However, some tree core samples collected could not be measured because of damage during coring, transportation and due to the presence of diffused rings.
- Since the individual trees were not tagged in the first inventory, it was difficult to monitor the growth of individual tree.
- It is recommended to at least take 100 readings for the Canopy measurement. However, due to time constraint, the NFI design required to take only 25 readings for estimation the canopy cover.

FOREST COVER

3 FOREST COVER

3.1 Background

Forest is defined as any land area with trees spanning more than 0.5 ha with trees higher than 5m in height and canopy cover of more than 10%. Forests is not restricted to the State Reserved Forest Land and include 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. Forests are then broadly categorized into two broad classes; Broadleaved Forest and Coniferous Forest and 10 major Forest types; Subtropical Forest (STFr), Warm Broadleaved Forest (WBFr), Chir Pine Forest (CPFr), Cool Broadleaved Forest (CBFr), Evergreen Oak Forest (EOFr), Blue Pine Forest (BPFr), Spruce Forest (SPFr), Hemlock Forest (HMFr), Fir Forest (FIFr) and Juniper Rhododendron Forest (JRFr).

For the purpose of NFI, each cluster plot has three plots; L, N and E, and each plot of 0.05 ha is assumed to represent a plot of 0.5 ha and other parameters were then estimated for the plot to be classified into “Forest” and “Non-Forest”. The parameters for defining forest area and the estimation methods are discussed in detail below;

3.1.1 Canopy Cover

Canopy cover is defined as the proportion of an area in the ground covered by the crowns of the trees and is measured using the GRS densitometer. 25 observations were recorded at a predefined interval of 4.2 m from the plot centre in all eight cardinal directions (Figure 3.1).

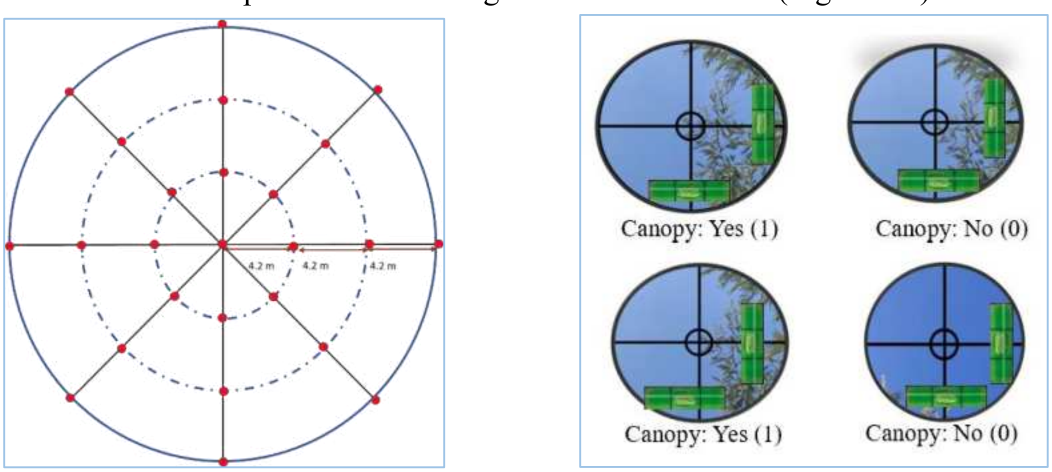


Figure 3.1 Points for measurement of canopy cover (left) and tally and non-tally of canopy as viewed through the densitometer

For each point, tally and non-tally were recorded. When viewing through the densitometer, if more than 50% of the inner black circle of the densitometer is covered by the canopy, then it is recorded as ‘1’ (tallied), otherwise recorded as ‘0’ (not tallied). The canopy cover percentage is then calculated by dividing the number of 1s by the total number of readings multiplied by 100 (DoFPS, 2021b).

This is one of the criteria for the classification of land into forest and non-forest as per the definition of forests adopted in Bhutan. The plots with a canopy cover of 10 % and more are then considered and assigned into Forest and Non-Forest depending on whether they also meet other forest criteria. Forest is then grouped into four broad categories of Open Forest, Moderately Dense Forest, Dense Forest and Very Dense Forest as per the canopy cover classification adopted in the Spatial Decision Support System of the Department. Forest area distribution by the Canopy cover is shown in Table 3.1.

Table 3.1 Forest area classification by Canopy Cover

Name	**Canopy**	**Forest Area (Ha)**	**% of country area**	**MoE (%)**	**Upper Limit**	**Lower Limit**
Open Forest	10-40	178,334.92	4.64	4.76	178,419.74	178,250.10
Moderately Dense Forest	40-60	421,795.56	10.99	2.47	421,899.75	421,691.37
Dense Forest	60-70	368,842.87	9.61	1.89	368,912.52	368,773.23
Very Dense Forest	70-100	1,707,572.07	44.47	0.83	1,707,714.40	1,707,429.74

There is often confusion between the canopy cover and canopy closure. A simple difference is explained in the paper, "*Assessing Forest canopies and understorey illumination: canopy closure, canopy cover and other measures*" (Jennings et al., 1999) and is reproduced below.
Canopy cover is defined as proportion of an area in the ground covered by the vertical projection of crowns of the trees while Canopy closure is the "proportion of the sky hemisphere obscured by vegetation when viewed from a single point.
Measurements of canopy cover assess the presence or absence of canopy vertically above a sample of points across an area of forest and is independent of height.

3.1.2 Height

The height of a tree is the length of the tree from Ground till the Tip and is measured using *Haglof* Laser Geo Hypsometer. For the NFI, the hypsometer was used to measure the total height, bole height, crown height and crown length, used to estimate important parameters. For the categorization of a particular land into Forest and Non-Forest, the stand height of the plot is taken into consideration. The total height of all trees in the plot is measured and averaged out to find the stand height to check whether the plot fulfills the forest criteria.

3.1.3 Area

If the plot, say the "L" plot fulfills the requirement of a minimum threshold of both canopy cover and stand height, the plot is assigned to "Forest", otherwise, it is assigned to "Non-Forest". Then, the same is repeated for "N" and "E". All plots in a cluster are assigned equal weights and proportions for the estimation of the total forest area, which shall be described in the Methodology; Area Estimation.

3.2 Methodology; Area Estimation

Forest area estimation is based on the total land area of Bhutan, and it is assumed to be error free. The area estimators used in NFI are ratio estimators (Cochran 1977). NFI plot design uses clusters of three circular plots, each plot was given equal weight and the proportion of forest or land stratum was estimated for each cluster plot and summed up to obtain the total proportion of that stratum (IPCC, 2003; Kleinn, 2013; Korhonen & Salmensuu, 2014; Vesa et al., 2014). A proportion of each stratum (Forest and Non-Forest) was estimated using the equation (3.1)

$$p_s = \frac{n_i}{n}$$

(3.1)

Where,

p_s is the proportion of the stratum;

n_i is the number of plot/plot centre falling under stratum i; and

n is total number of plots/plot centres.

The area of interest is estimated multiplying the proportion with the total study area equation (3.2).

$$a_i = A \, x \, p_s$$

(3.2)

Where,

a_i is area of interest (e.g., forest);

A is total area of the country/study area; and

p_s is the proportion of the stratum

In short, the area estimated of a land stratum (e.g., forest, non-forest, forest type) is the number of plot centres in the stratum which are forested, divided by the total number of plot centres and multiplied by the known land area. The variance is estimated using the parametric population variance formula:

$$\sigma^2 = p * q$$

(3.3)

Where,

p is the true (parametric) proportion of target elements in the population (e.g., Forest, Non-Forest, Forest Type), and

$$q = 1\text{-}p$$

Accounting of the non-response or inaccessible plots (IA) was an important consideration as the majority of the IA were in the high-altitude northern regions which are under permanent snow cover or glacier, and, generally devoid of vegetation cover which may have resulted in over or under estimation of the forest area. Therefore, weight for the IA cluster plots was manually assigned by overlaying each IA plots on Forest Type Map of Bhutan 2022 and Land Use and Land Cover Map 2016 using QGIS software and assigned qualitative class of forest and non-forest for each cluster plot. Further, these qualitative parameters were validated with high resolution google earth imageries, Open Foris Collect Earth software and consultation with local experts.

3.3 Forest Cover by Different Categories

3.3.1 Forest Cover by Land Area

The total land cover in Bhutan is first categorized into Forest and Non-Forest and subsequently, the forest cover in different land categories is estimated and described thereafter. Table 3.2 shows the Forest and Non-Forest area in Bhutan. The total Forest area is estimated to be 69.71 % (2.68 million ha) of the total land area while 30.29 % (1.16 million ha) of the total land area is estimated for the Non-Forest area.

Table 3.2 Total land area by Forest and Non-Forest

Land Type	Area (ha)	Forest Cover (%)	MoE (%)	Lower Limit	Upper Limit
Forest	2,676,545.42	69.71	1.87	2,626,585.13	2,726,505.71
Non-Forest	1,162,854.58	30.29	1.87	1,141,148.78	1,184,560.38

The Forest and Non-Forest area is strictly aligned with the technical definition of Forest and is independent of the land ownership. For e.g., if a private forest in Bumthang fulfills the definition of Forest, then it has been categorized into Forest and otherwise. Further, forest cover reported in this report does not differentiate between the natural and manmade forests whilst it is fair to assume that more than 90% of the Forest of Bhutan is natural forest with limited man-made forest in Southern Bhutan.

The estimates hereafter shall take into account only the “Forest” areas and the estimates thereof are discussed by different categories.

3.3.2 Forest Cover by Dzongkhag

Figure 3.2 and Table 3.3 shows the total forest cover in each Dzongkhag and the percentage of forest cover by Dzongkhag area. Wangdue Phodrang has the greatest area under forest cover, with an estimated area of 258,969.43 ha, followed closely by Zhemgang Dzongkhag with an estimated area of 223,067.45 ha. About 94 % of the total area of Zhemgang Dzongkhag is Forest, making Zhemgang the Dzongkhag with the greatest Forest cover while the total forest cover in Wangdue

Phodrang accounts for 65 % of the total Dzongkhag area. Gasa has the smallest area with forest cover (21 %) accounting for a total of 65,468.32 ha of forest cover. On the other hand, Tsirang has the smallest forest area (54,380.94) and accounts for 82 % of the total land area of Tsirang.

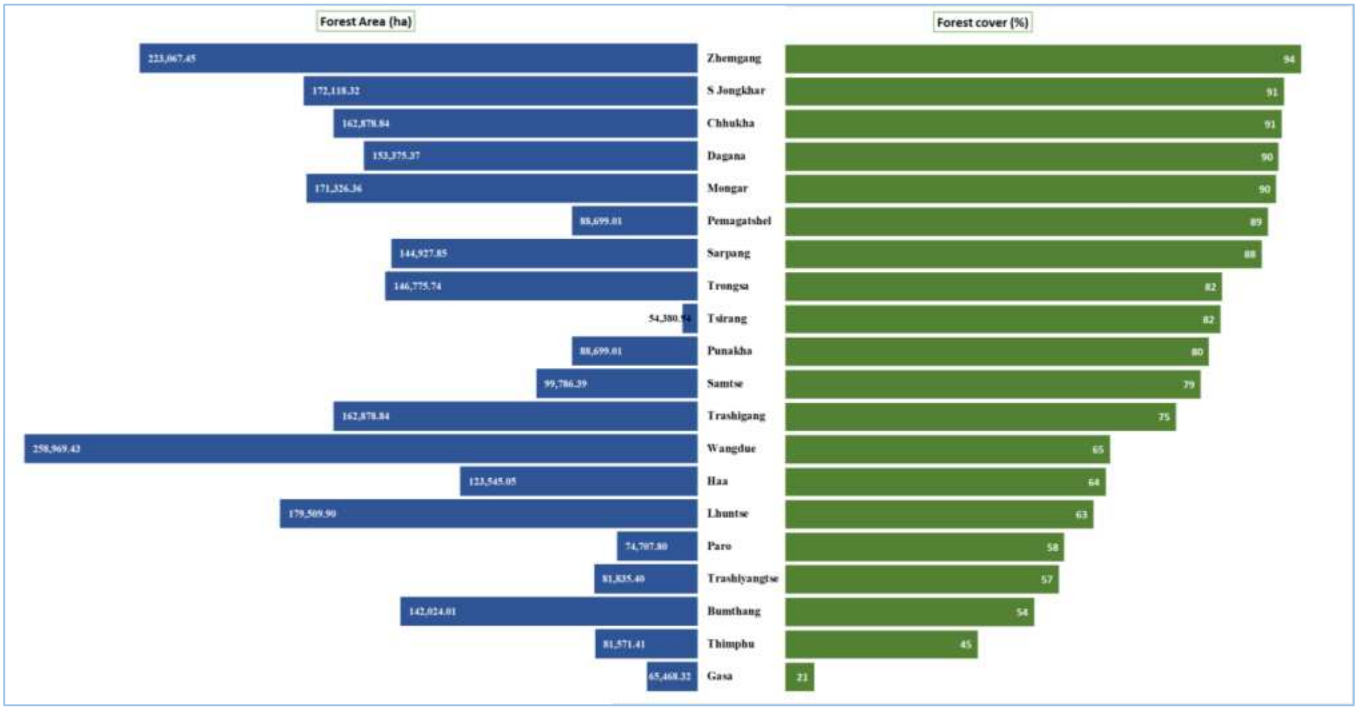


Figure 3.2 Forest cover and percentage forest cover in each Dzongkhag

Table 3.3 Forest cover by Dzongkhag

Dzongkhag	**Forest Area (ha)**	**Forest cover (%)**	**MoE (%)**	**Lower Limit**	**Upper Limit**
Bumthang	142,024.01	53.69	2.36	138,673.49	145,374.53
Chhukha	162,878.84	91.00	1.35	160,673.83	165,083.84
Dagana	153,375.37	90.50	1.39	151,247.52	155,503.22
Gasa	65,468.32	20.56	1.91	64,216.44	66,720.19
Haa	123,545.05	64.46	2.26	120,747.43	126,342.67
Lhuentse	179,509.90	62.62	2.29	175,400.83	183,618.97
Mongar	171,326.36	90.14	1.41	168,909.73	173,743.00
Paro	74,707.80	58.23	2.33	72,964.63	76,450.96
Pemagatshel	88,699.01	88.89	1.49	87,380.18	90,017.84
Punakha	88,699.01	80.00	1.89	87,020.41	90,377.61
Samdrup Jongkhar	172,118.32	91.32	1.33	169,825.25	174,411.38
Samtse	99,786.39	78.75	1.94	97,855.11	101,717.66
Sarpang	144,927.85	87.98	1.54	142,698.12	147,157.57
Thimphu	81,571.41	45.18	2.35	79,650.78	83,492.04

Trashigang	162,878.84	75.06	2.05	159,544.73	166,212.95
Trashi Yangtse	81,835.40	57.41	2.34	79,920.88	83,749.92
Trongsa	146,775.74	82.01	1.82	144,108.21	149,443.27
Tsirang	54,380.94	81.75	1.83	53,387.08	55,374.80
Wangdue Phodrang	258,969.43	65.14	2.25	253,130.88	264,807.99
Zhemgang	223,067.45	93.89	1.13	220,539.49	225,595.42

3.3.3 Forest Cover by Forest Type

Broadleaved Forest constitutes 67.99 % of the total Forest in Bhutan with a total forest area of 1,819,649.63 ha. Coniferous Forest constitute only 32.01 % of the forest area and covers an area of 856,895.79 ha (Table 3.4). These are further segregated into different Forest types in Table 3.5 and Figure 3.3.

Table 3.4 Forest cover by Forest Class

Forest Class	Forest Area (ha)	Percentage of Country Area	Percentage of Forest Area	MoE (%)	Lower Limit	Upper Limit
Broadleaved	1,819,649.63	47.39	67.99	2.21	65.78	70.19
Coniferous	856,895.79	22.32	32.01	2.21	29.81	34.22

Table 3.5 Forest cover by Forest Type

Forest type	Forest Area	Forest Cover (%)	MoE (%)	Lower Limit	Upper Limit
Subtropical Forest	356,115.97	13.31	1.61	350,393.75	361,838.18
Chir Pine Forest	78,403.59	2.93	0.80	77,778.09	79,029.09
Warm Broadleaved Forest	668,674.38	24.98	2.05	654,978.72	682,370.04
Evergreen Oak Forest	40,653.71	1.52	0.58	40,418.48	40,888.95
Cool Broadleaved Forest	754,205.57	28.18	2.13	38,153.07	770,258.07
Blue Pine Forest	103,482.18	3.87	0.91	102,538.30	104,426.06
Spruce Forest	42,237.62	1.58	0.59	41,988.58	42,486.67
Hemlock Forest	130,408.66	4.87	1.02	129,080.37	131,736.96
Fir Forest	432,671.66	16.17	1.74	425,135.85	440,207.47
Juniper Rhododendron Forest	69,692.08	2.60	0.75	69,167.00	70,217.16

Cool Broadleaved Forest dominates the Forests in Bhutan accounting for 28.18 % of the total forest. Cool Broadleaved Forest and Warm Broadleaved Forest together account for 53.16 % of the total Forest area in Bhutan. Evergreen Oak Forest and Spruce Forest has the smallest area coverage constituting 1.52 % and 1.58 % of the total Forest respectively. The total forest area (ha) and forest cover (%) for each forest type are shown in Figure 3.3.

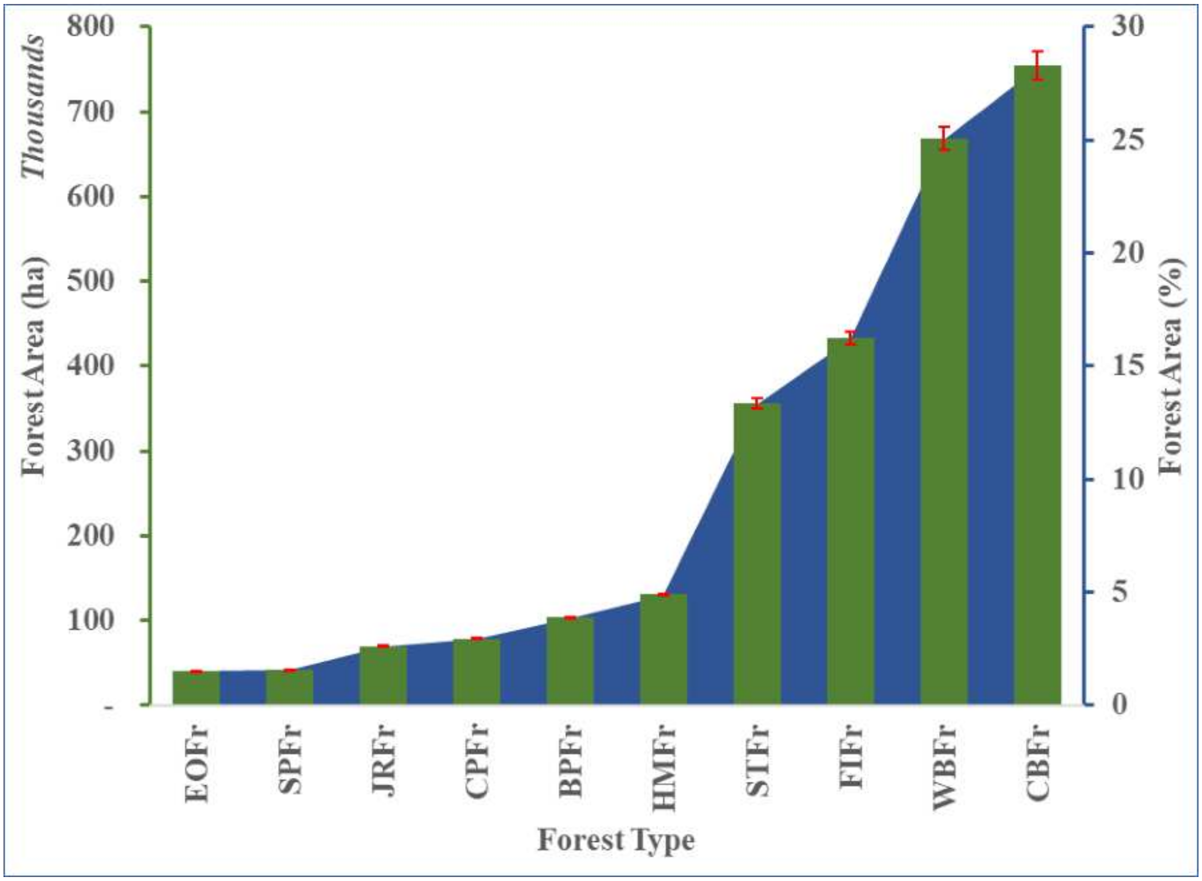


Figure 3.3 Comparison of Forest area and forest area percentage by different Forest Type

3.3.4 Forest Cover by Elevation Class

The majority of the Forests (32 %) is found in the elevation class of 2000-3000 *m.a.s.*l and constitutes about 855,575.87 ha of forest. Forest area decreases gradually in both directions; upper and lower elevations, from the 2000-3000 *m.a.s.l.* The least forest cover is estimated for elevations above 4000 *m.a.s.l*, which is dominated by Juniper Rhododendron Forest (Figure 3.4).

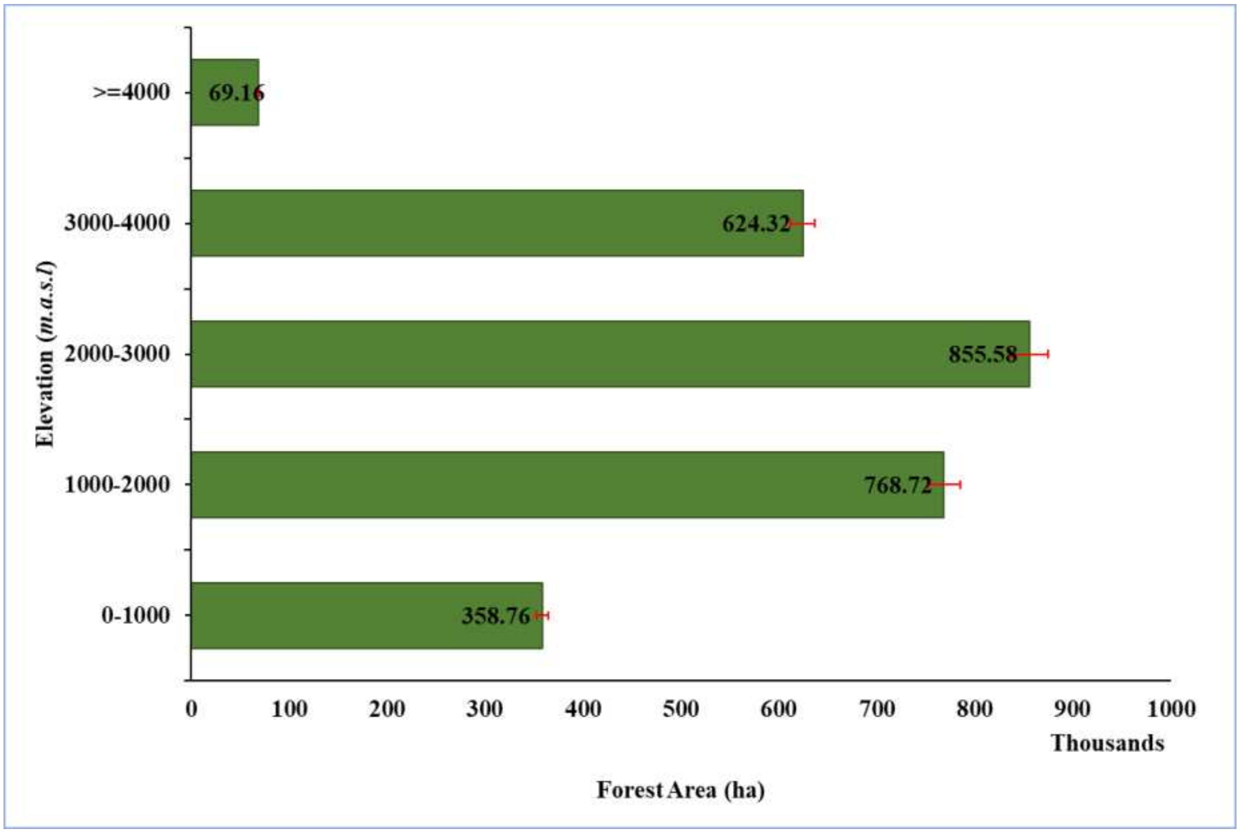


Figure 3.4 Forest cover by Elevation

3.4 Discussion

The 2nd NFI estimates a forest cover of 69.71 % in comparison to an estimated forest cover of 71.13 % during the 1st NFI. Samdrup Jongkhar and Samtse saw a significant increase in forest cover percentage while there is a decrease in forest cover in Gasa, Haa, Lhuentse, Trashi Yangtse and Wangdue Phodrang Dzongkhag (Figure 3.5). Forest area is estimated from the total accessible plot and while no specific reasons can be ascertained for change in forest cover, a strong correlation was observed between the number of accessible plots and the forest area as well as accounting of the inaccessible plots. Most of the inaccessible plots of NFI 1 were Non-Forest which is assumed to have equal probability of being classified into Forest and Non-Forest. For example, out of the total 2,424 CP, 1685 were accessible and 739 was inaccessible. 1253 CP out of 1685 accessible plot were classified as Forest and accordingly, a forest cover of 71.35 % Forest cover was reported. Therefore, it is assumed that the proportion of forest and non-forest were same for accessible and inaccessible plots. Further, change in canopy measurement method also has also contributed to change in forests cover.

During the 2nd NFI, the plot accessibility percentage is 81 % as compared to 70% accessibility in the 1st NFI. It has been observed that most of the inaccessible plots fall either in the snow-capped and glacial mountain in the North or the dense forest separated by high cliffs and swollen rivers in central and southern Bhutan. A significant part of the unenumerated plots from 1st NFI were enumerated in the 2nd NFI since the NFI crew had a proper understanding of the season and location of the plots as a result of the decentralization of the fieldwork to the respective field office. This was implemented as a recommendation from the lessons learned from the implementation of the 1st NFI.

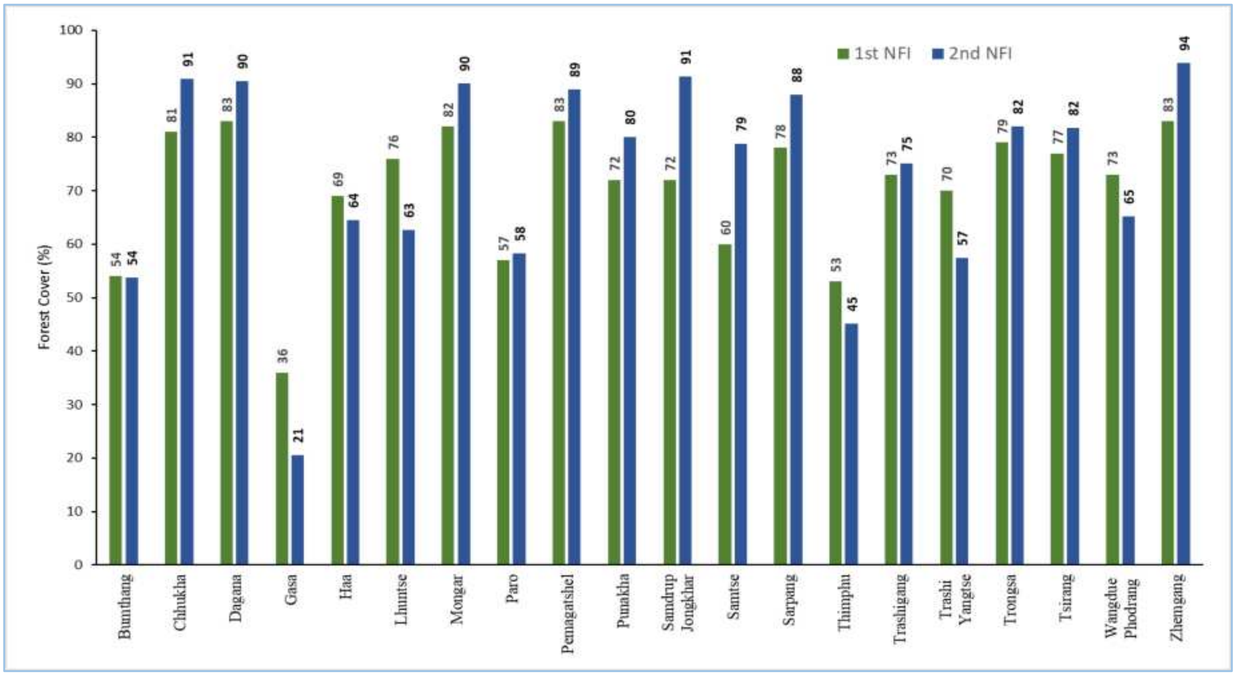


Figure 3.5 Comparison of forest cover percentage in different Dzongkhag (1st and 2nd NFI).

The overall decrease in forest cover can also be attributed to the land use changes because of the increasing developmental activities and conversion of private Forest lands to other land uses. Forestry clearance has been issued for the allotment of 71,241.95 ha of SRF for developmental activities. Further, about 1.57 million m^3 of timber has been allotted directly by the Department from 2016-2022 to meet the rural and commercial needs of the people (FRMD, 2016a, 2017, 2018a, 2019, 2020, 2021) in addition to timber allotted through Natural Resources Development Corporation Limited (NRDCL) and removal of forest produce from private registered land. Private Forest constitute 2.78 % of the total Forest land in the country.

Further, Evergreen Oak Forest constitutes only 1.52 % of the total Forest which is in contrast to the general observation wherein, Oak of different species are found spread across different elevations in Bhutan. The Oaks are often found mixed with other Broadleaved species such as *Castanopsis* spp*., Schima* spp*., Persea* spp., *Litsea* spp., *Pinus wallichiana, Symplocus* spp*., Acer campbelli.* The elevation ranges of the Evergreen Oak Forest overlaps with that of the Warm Broadleaved Forest and Cool Broadleaved Forest. Therefore, majority of the 1.52 % of the Evergreen Oak Forest is pure oak stands and other Oak Forests may have been mis-classified to Cool and Warm Broadleaved Forest.

STEM DENSITY

4 STEM DENSITY

4.1 Introduction

Stem density refers to the number of tree stems or plants per unit area (Kershaw, et al., 2017) or any other forest stand parameters. However, this chapter reports only tree count and sapling count as basal area and volume are reported separately. The tree count or sapling count per unit area measures how closely spaced individual trees or saplings or plants are in the given area. This is important information to assess the effectiveness of the forest management and optimize management interventions to improve stand growth.

The stem density for each subplot is reported as tree count and sapling count based on diameter at breast height. The stem density is estimated using the equation (4.1).

$$\boldsymbol{S_d} = \frac{\boldsymbol{T_n}}{\boldsymbol{A_p}} \tag{4.1}$$

Where,

S_d is stem density, (tree ha^{-1} / sapling ha^{-1})
T_n is number of trees in plot
A_p is plot area (ha)

The mean tree count for each CP is the mean of tree count per ha of all accessible plots in CP by Forest and Non-Forest. Mean tree count per ha at cluster was used as a basis for aggregation and computation of estimates at different forest stratum or reporting units. The total tree count in a forest or any domain of interest was computed by multiplying the tree count per hectare for that domain with an estimated area of the same domain or stratum (Gregoire & Valentine, 2007; Tomppo, 2006).

4.2 Stem Density by Different Categories

4.2.1 Stem Density at National Level

A total of 81,709 trees were recorded during the NFI, from which 80,270 trees and 3,037 trees were recorded in Forest and Non-Forest respectively. Similarly, from the total of 43,619 individual saplings recorded from NFI plots, 41,266 saplings were recorded in Forest and 2,343 saplings in Non-Forest. The stem density varies significantly between Forest and Non-Forest land. Tree or sapling count in Non-Forest land constitute all tree species outside the forest and include trees in orchards as well as trees in the urban area where land area is not defined as Forest as described in Chapter 3. Tree and sapling density in Forest is 377 tree ha^{-1} and 195 sapling ha^{-1} respectively while tree and sapling density in Non-Forest land is 23 tree ha^{-1} and 76 saplings tree ha^{-1} respectively. Table 4.1 and Table 4.2 shows the tree count per ha and total tree count in Forest and Non-Forest land respectively. Table 4.3 and Table 4.4 shows the sapling density and total sapling count in forest and non-forest land respectively.

Table 4.1 Tree density in Forest and Non-Forest

Land Type	Tree Count (No. ha^{-1})	MoE (%)	Lower Limit	Upper Limit
Forest	377	3	366	387
Non-Forest	23	21	18	28

Table 4.2: Total tree count in Forest and Non-Forest

Land Type	Tree Count (No.)	MoE (%)	Lower limit	Upper limit
Forest	1,008,117,141	3	974,582,090	1,041,652,192
Non-Forest	26,700,949	21	21,190,870	32,211,029

Table 4.3:Sapling density in Forest and Non-Forest

Land Type	Sapling Count (No. ha^{-1})	MoE (%)	Lower Limit	Upper Limit
Forest	195	6	184	207
Non-Forest	76	47	40	111

Table 4.4 Total sapling count in Forest and Non-Forest

Land Type	Sapling Count (No.)	MoE (%)	Lower Limit	Upper Limit
Forest	523,201,912	6	490,233,493	556,170,332
Non-Forest	88,113,132	47	46,699,661	129,526,602

4.2.2 Stem Density by Dzongkhag

This section provides the estimate of tree and sapling counts for each *Dzongkhag.* Table 4.5 and Table 4.6 shows the tree density in twenty *Dzongkhag*. The tree density is greatest in the Pemagatshel Dzongkhag (490 tree ha^{-1}) while it is estimated to be lowest in Samtse Dzongkhag (263 tree ha^{-1}).

Table 4.5 Tree count per ha by Dzongkhag

Dzongkhag	Tree Count (No. ha^{-1})	MoE (%)	Lower limit	Upper Limit
Bumthang	430	11	384	476
Chhukha	303	12	268	338
Dagana	450	9	410	490
Gasa	307	22	241	374
Haa	405	13	351	459
Lhuentse	313	12	274	352
Mongar	351	12	307	394
Paro	363	15	309	416
Pemagatshel	490	13	424	556
Punakha	359	13	313	406
Samdrup Jongkhar	311	10	282	341
Samtse	263	11	235	292

Sarpang	356	9	324	387
Thimphu	415	14	356	475
Trashigang	417	14	360	474
Trashi Yangtse	408	13	354	462
Trongsa	412	11	367	458
Tsirang	376	17	311	441
Wangdue Phodrang	393	9	357	428
Zhemgang	384	8	355	413

The sapling density is smallest in Thimphu Dzongkhag with 62 saplings per ha and greatest in Gasa Dzongkhag with 551 saplings per ha as shown in Table 4.6. In general, the average sapling density varies from about 25% to 50% from National level estimate except for Dzongkhag with lower sapling density like Thimphu (62 saplings ha^{-1}) and Samtse (88 saplings ha^{-1}), and higher saplings like Gasa (551 saplings ha^{-1}).

Table 4.6 Sapling density by Dzongkhag

Dzongkhag	Sapling count (No. ha^{-1})	MoE (%)	Lower Limit	Upper Limit
Bumthang	148	19	119	177
Chhukha	214	18	175	252
Dagana	161	18	132	189
Gasa	551	57	235	867
Haa	226	25	170	282
Lhuentse	164	25	122	206
Mongar	155	20	123	186
Paro	263	28	190	337
Pemagatshel	281	31	194	367
Punakha	172	33	116	229
Samdrup Jongkhar	192	14	165	219
Samtse	88	22	68	107
Sarpang	157	13	137	178
Thimphu	62	28	45	79
Trashigang	247	17	206	288
Trashi Yangtse	243	32	165	321
Trongsa	241	27	177	306
Tsirang	200	27	147	252
Wangdue Phodrang	205	20	164	246
Zhemgang	176	12	155	197

Figure 4.1 and Figure 4.2 shows the total tree and sapling count respectively in Dzongkhags. Wangdue Phodrang Dzongkhag has the greatest total tree and sapling count with 101 million trees and 53 million saplings. The total tree count is smallest in Gasa and Tsirang Dzongkhag with 20 million trees each while the smallest sapling count is recorded in Thimphu Dzongkhag with 5 million saplings.

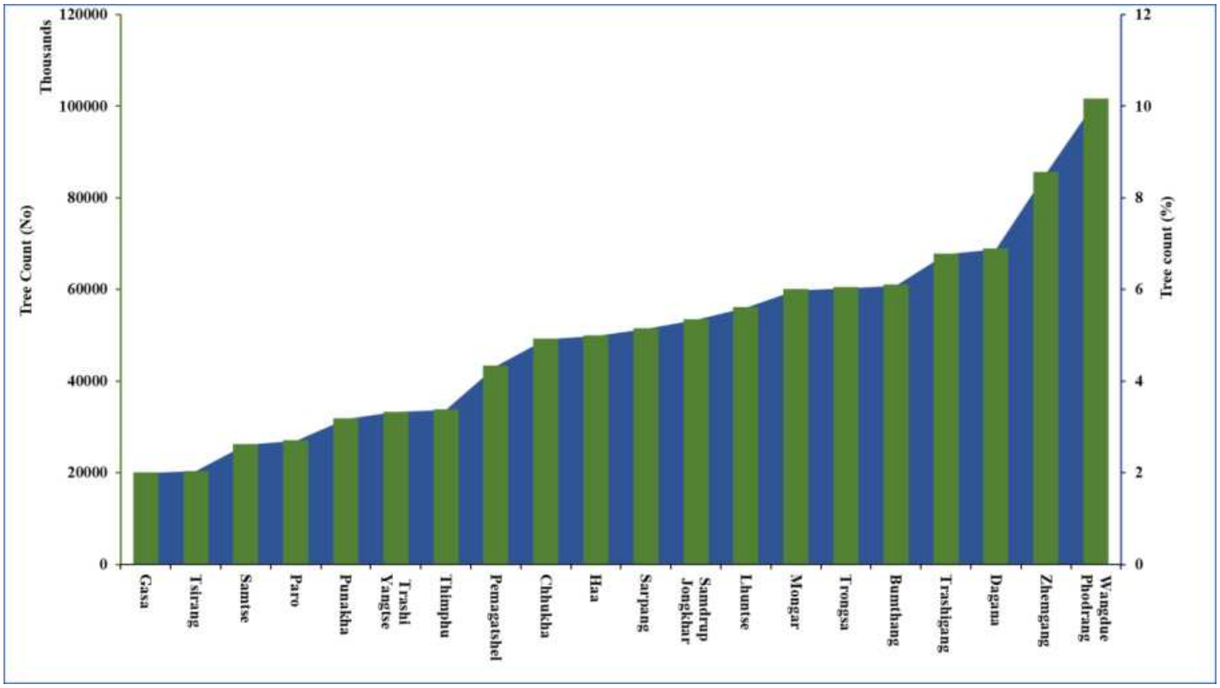


Figure 4.1 Total tree count by Dzongkhag

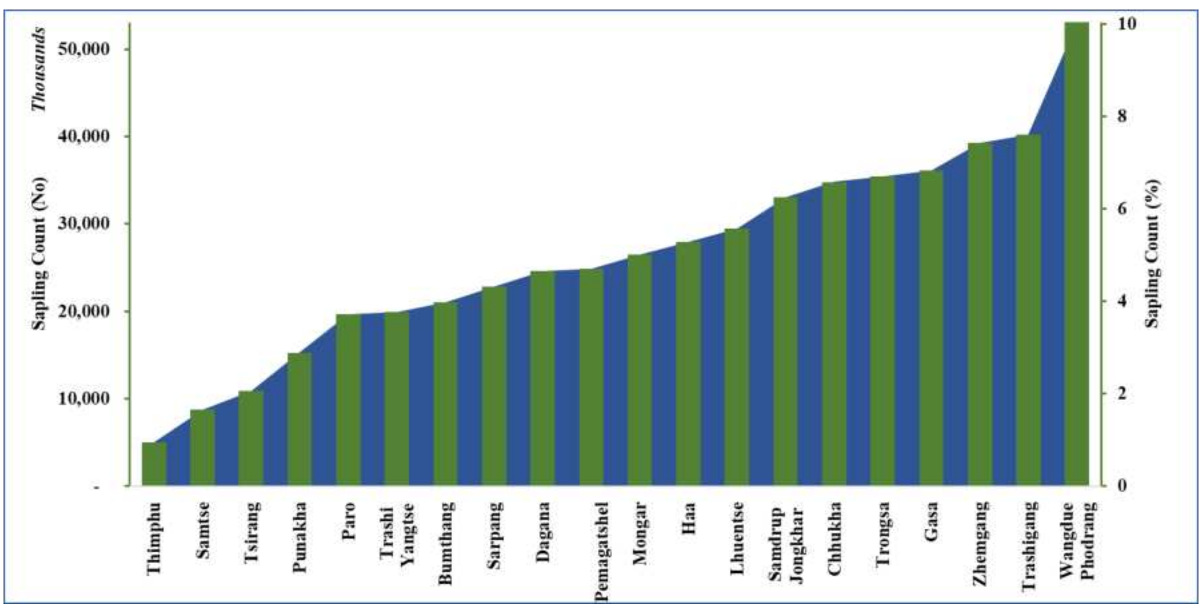


Figure 4.2 Total sapling count by Dzongkhag

4.2.3 Stem Density by Forest Type

This section provides the estimates of tree count and sapling count by Forest Type. Table 4.7 and Table 4.8 shows the tree density and total tree count in Broadleaved and Coniferous Forest and Figure 4.3 shows the comparison of total tree count in Broadleaved and Coniferous Forests. Tree density is slightly greater in Broadleaved Forest than in the Coniferous Forest. However, Broadleaved Forest constitutes more than two third of the total tree count.

Table 4.7 Tree density by Forest Class

Forest Class	Tree Count (No. ha^{-1})	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	378	3	366	390
Coniferous Forest	374	5	354	394

Table 4.8 Total tree count by Forest Class

Forest Class	Tree Count (No)	MoE (%)	Lower Limit	Upper Limit
Broadleaved forest	687,617,516	4	658,851,047	716,383,984
Coniferous forest	320,209,131	7	299,099,908	341,318,355

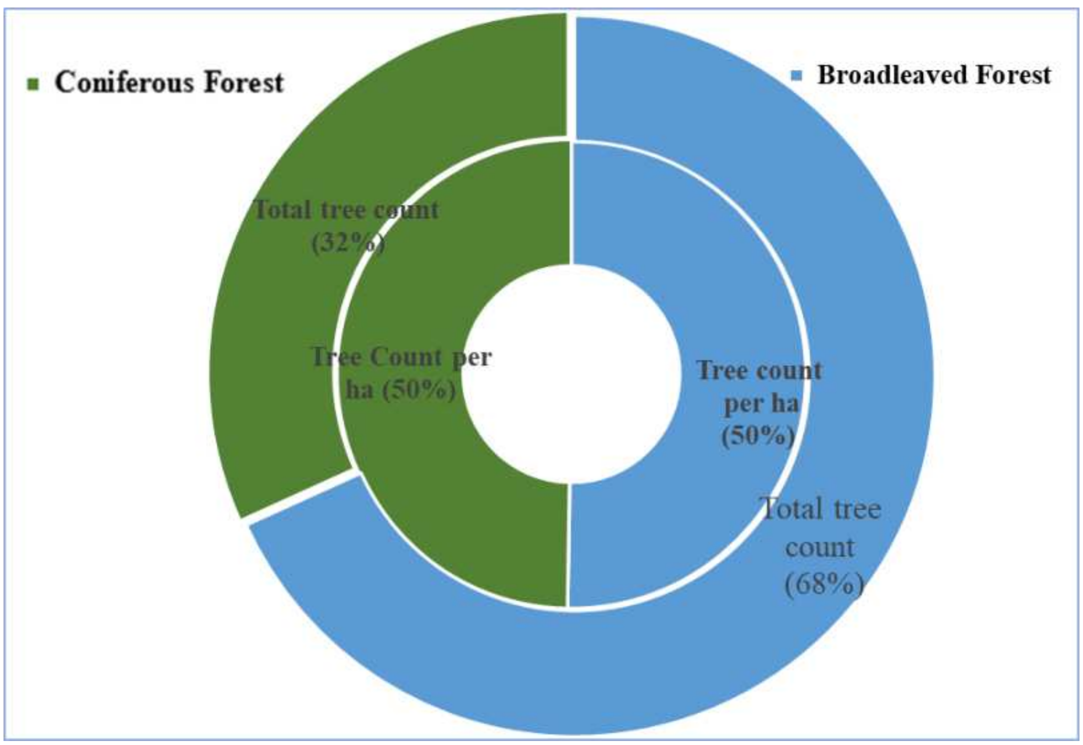


Figure 4.3 Comparison of tree count in Broadleaved and Coniferous Forests

Table 4.9 and Table 4.10 shows the sapling density and total sapling count in Broadleaved and Coniferous Forests. Contrary to the tree density, the sapling density is greater in Coniferous Forest than in Broadleaved Forest.

Table 4.9 Sapling density in Forest Class

Forest Class	Sapling Count (No. ha^{-1})	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	180	6	169	190
Coniferous Forest	234	13	203	264

Table 4.10 Total Sapling count in Forest Class

Forest Class	Sapling Count (No)	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	326,762,297	7	305,427,976	348,096,618
Coniferous Forest	200,177,245	14	172,986,195	227,368,296

Forest classes are further classified into ten Forest Types as described in Chapter 2. Table 4.11 shows the tree density in different Forest Types. Tree density in the different Forest Type range from 254 to 426 trees per ha and the tree count in all Forest Types except Subtropical, Chir Pine, Warm Broadleaved and Juniper Rhododendron Forests are greater than the National average.

Table 4.11 Tree density by Forest Type

Forest Type	Tree Count (No. ha^{-1})	MoE (%)	Lower Limit	Upper Limit
Subtropical Forest	310	6	292	329
Chir Pine Forest	254	19	206	302
Warm Broadleaved Forest	375	5	356	395
Evergreen Oak Forests	417	19	339	494
Cool Broadleaved Forest	417	5	395	438
Blue Pine Forest	426	15	361	491
Spruce Forest	401	16	336	467
Hemlock Forest	406	14	350	463
Fir Forest	402	7	376	429
Juniper Rhododendron Forest	269	22	209	329

Figure 4.4 shows the total tree count by Forest Type. Overall, Broadleaved Forest dominates the tree count with Cool Broadleaved and Warm Broadleaved Forest constituting 55% of all estimated trees in the country. Total tree count is smallest in the Chirpine, Juniper Rhododendron, Evergreen Oak and Spruce Forest, all contributing only 2% each to the total tree count in the Forest.

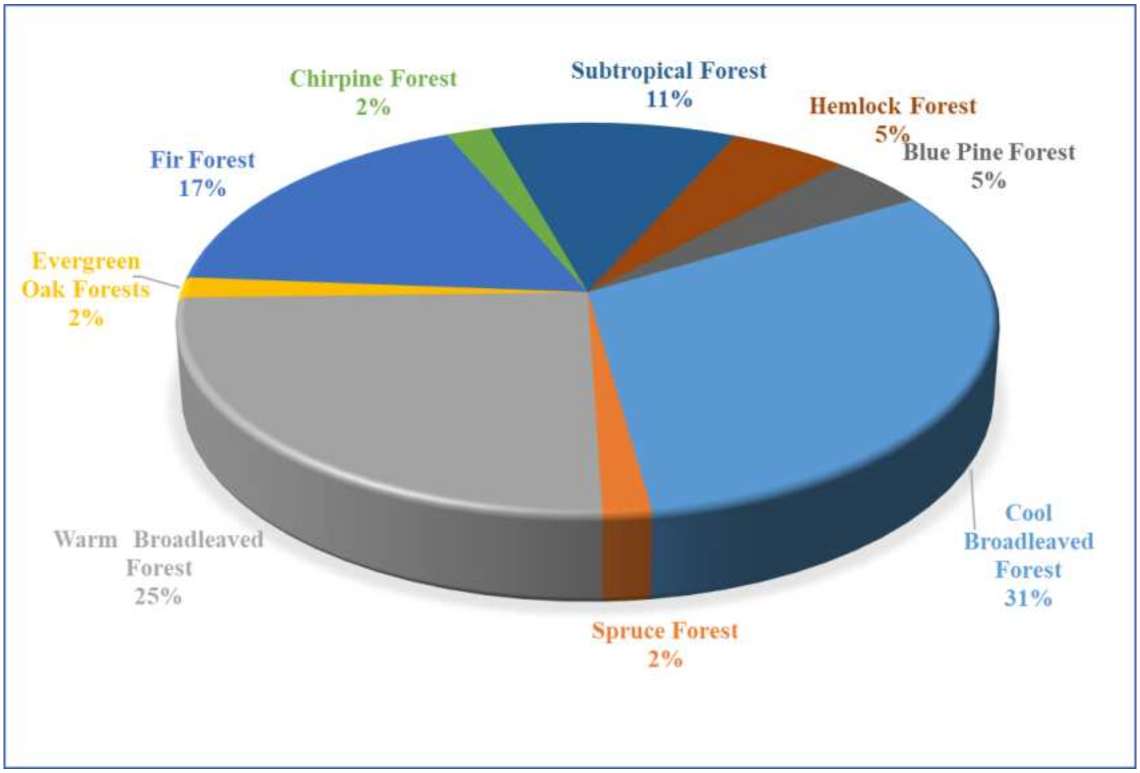


Figure 4.4: Distribution of total tree count by Forest Type

Table 4.12 shows the sapling density by Forest Types. Evergreen Oak forest has the greatest saplings density while Chir Pine Forest has the least sapling density. The sapling density is greatest in the Evergreen Oak Forest (350 sapling ha^{-1}) and smallest in the Chir Pine Forest (128 sapling ha^{-1}).

Table 4.12 Sapling density by Forest Type

Forest Type	Sapling (No. ha^{-1})	MoE (%)	Lower Limit	Upper Limit
Subtropical Forest	161	8	147	174
Chir Pine Forest	128	30	90	167
Warm Broadleaved Forest	177	10	159	194
Evergreen Oak Forests	350	38	218	482
Cool Broadleaved Forest	182	10	164	200
Blue Pine Forest	206	27	150	262
Spruce Forest	179	41	105	253
Hemlock Forest	203	28	146	260
Fir Forest	271	17	226	316
Juniper Rhododendron Forest	271	57	117	425

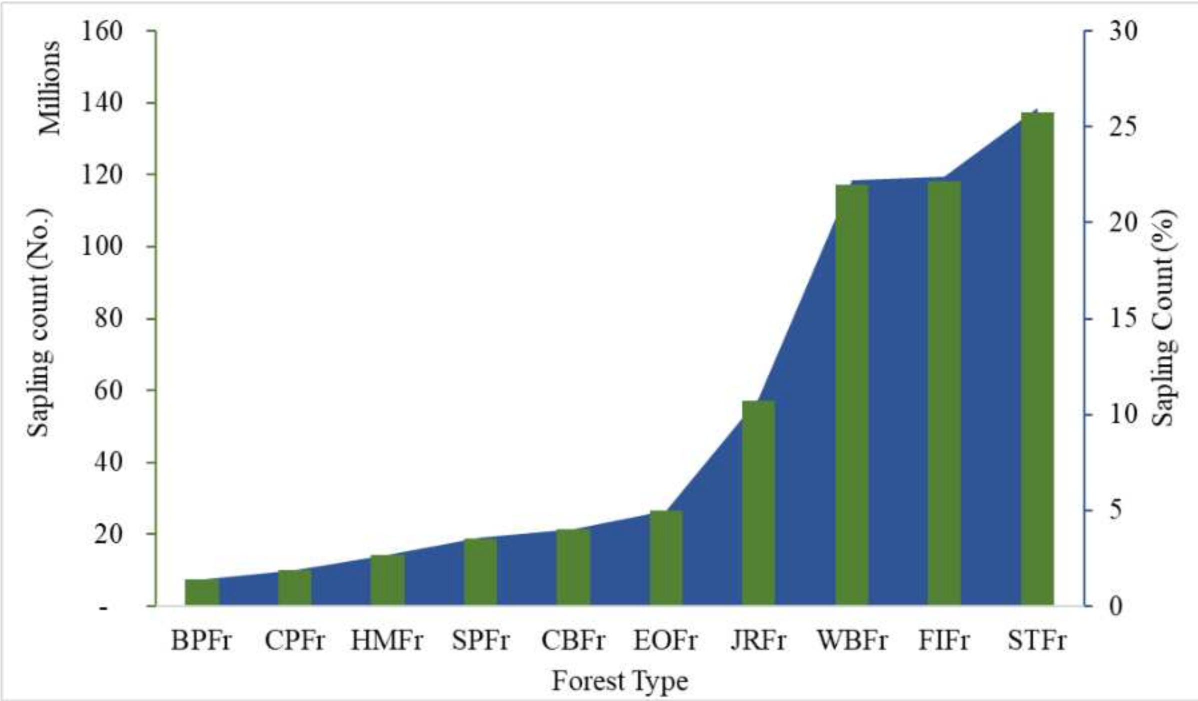


Figure 4.5 Total sapling count by Forest Type

4.2.4 Stem Density by Elevation

Table 4.13 shows the tree density by elevation range in Bhutan's Forests. The tree density increases with increasing elevation and peaks in elevation ranges of 2000-3000 *m.a.s.l* and then declines linearly. The elevation class 2000-3000 also recorded the greatest tree count (357 million) while the smallest tree count of 18 million trees is recorded at an elevation >= 4000 *m.a.s.l* (Figure 4.6).

Table 4.13: Tree density by Elevation

Elevation (*m.a.s.l*)	Tree Count (No. ha^{-1})	MoE (%)	Lower Limit	Upper Limit
<1000	301	6	283	320
1000-2000	362	5	344	381
2000-3000	421	5	401	441
3000-4000	397	6	374	419
>=4000	233	34	153	314

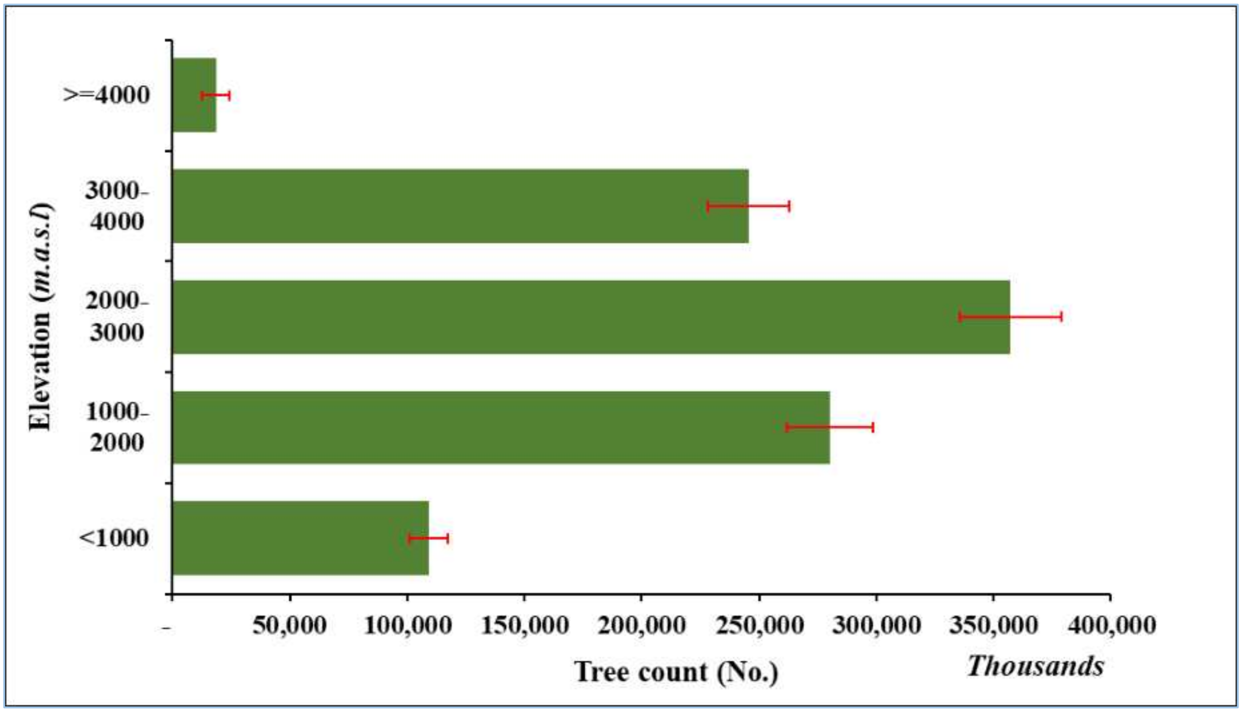


Figure 4.6 Total tree count by Elevation

Table 4.14 shows the sapling density by elevation. Sapling density is smallest in the elevation below 1000 *m.a.s.l* with 159 saplings ha^{-1}. The sapling density increase linearly from <1000 *m.a.s.l* to >=4000 *m.a.s.l*. The greatest sapling density is recorded >=4000 *m.a.s.l* with 273 saplings ha-^{1} while the greatest number of the total sapling is recorded between 2000 – 3000 *m.a.s.l* (162 million). The elevation range >= 4000 *m.a.s.l* recorded 20 million saplings (Figure 4.7).

Table 4.14 Sapling density by Elevation

Elevation	**Sapling count (No. ha^{-1})**	**MoE (%)**	**Lower Limit**	**Upper Limit**
<1000	159	9	145	174
1000-2000	173	10	156	190
2000-3000	190	10	171	208
3000-4000	252	15	215	290
>=4000	273	47	144	402

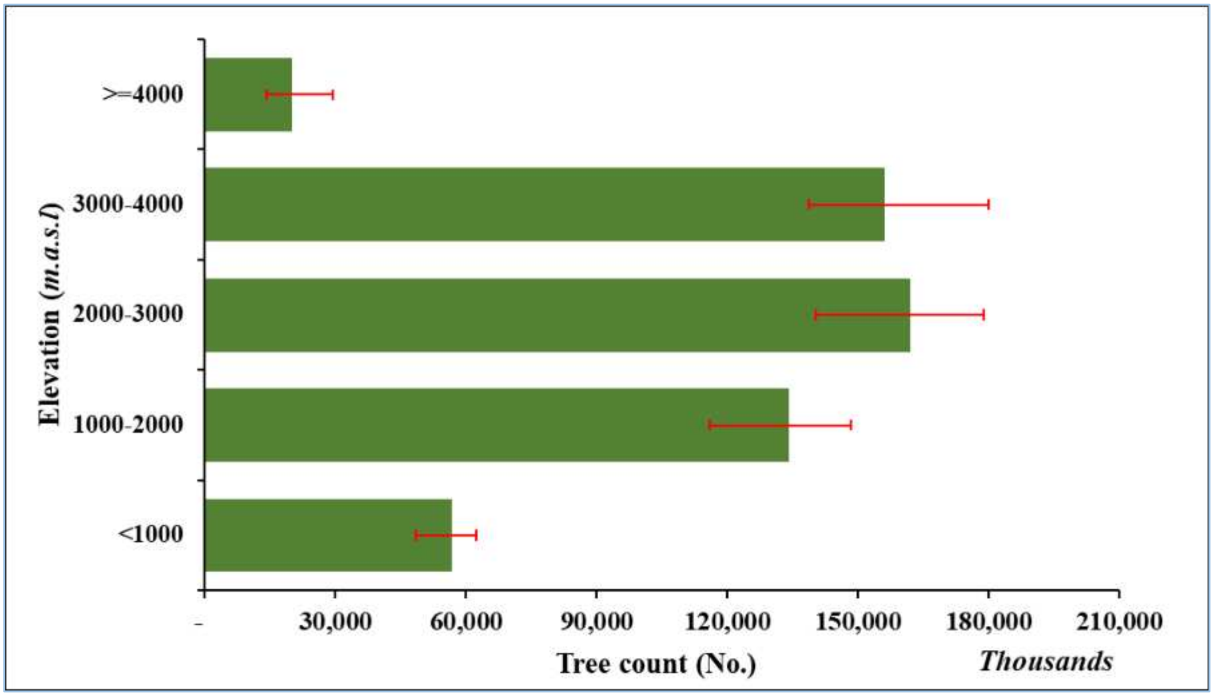


Figure 4.7 Total sapling count by Elevation

4.2.5 Stem Density by DBH Class

Diameter class is an important parameter for sustainable forest management as it provides information on the age and structure of the Forest stand. Table 4.15 shows the tree density by DBH class. 83,306 trees were recorded in the NFI with an average DBH of 26.8 cm. The tree density is greatest in the smallest DBH class of 10-20 and 20-30, which together constitute 72% of the total tree per hectare in the Forest. The DBH class >= 100 cm includes all trees which has DBH of 100 or more. The maximum DBH recorded during this NFI is 260 cm for a *Cupressus corneyana* (*Tsenden shing*) under Kazhi Gewog.

Table 4.15 Tree density by DBH Class

DBH Class (cm)	Tree Count (No. ha^{-1})	MoE (%)	Lower Limit	Upper Limit
10-20	191	4	183	198
20-30	80	4	77	83
30-40	42	4	40	44
40-50	23	4	22	24
50-60	14	5	14	15
60-70	9	6	9	10
70-80	6	7	6	6
80-90	4	8	4	5
90-100	3	10	2	3
>=100	4	9	4	5

Figure 4.8 shows the decreasing number of trees with a greater diameter class with the smallest tree density in DBH class of 90-100 cm. Further, Figure 4.8 shows the proportion of total estimated trees in the Forest. About 72% of trees have DBH less than 30 cm.

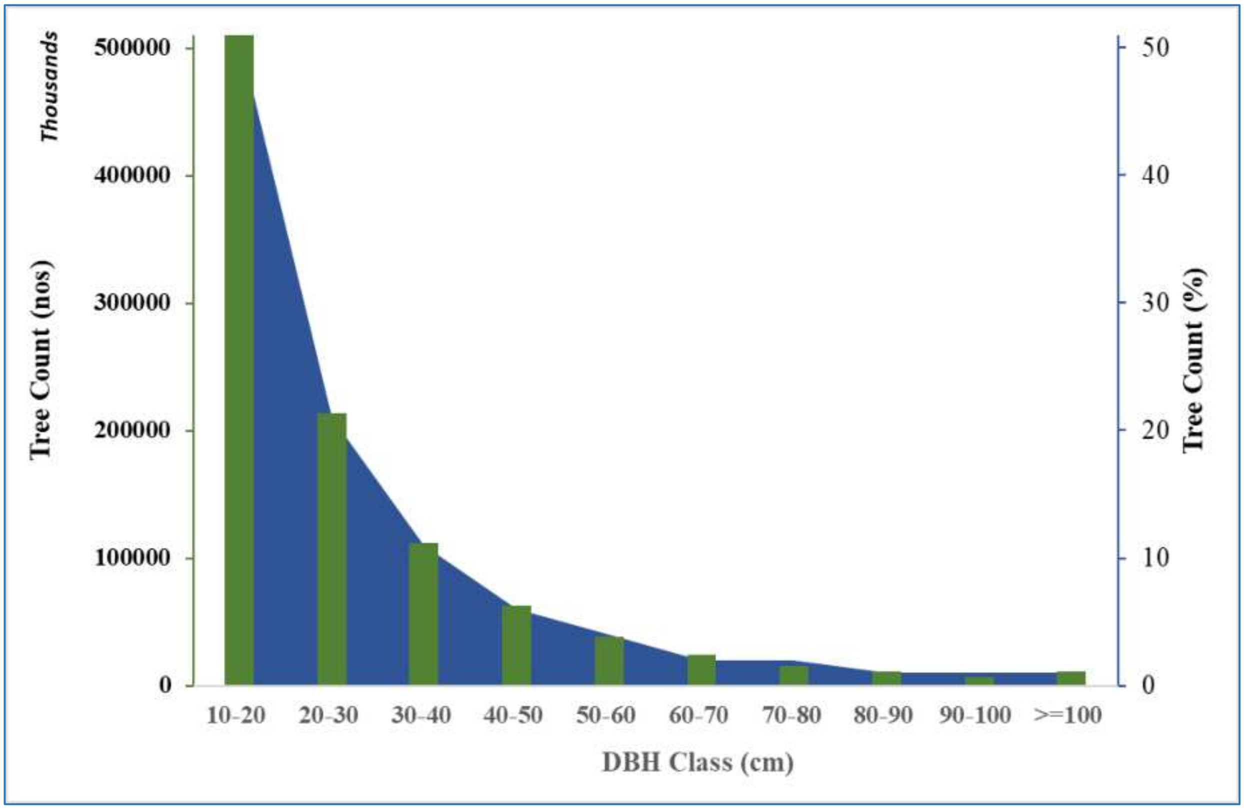


Figure 4.8: Comparison of tree count and proportion of total trees in different DBH Class

4.2.6 Stem Density by Height Class

The tree height is classified into 9 classes of <5m, 5-10 m, 10-15 m, 15 -20 m. 20-25 m, 25- 30 m, 30-35m, 35-40 m, >=40 m. The minimum height of tree recorded in the NFI is 1.5 m and the mean height of all trees is 13 m. The maximum height of the tree is 83.3 m for *Cupressus corneyana* (*Tsenden shing)* under Kazhi Gewog, Wangdue Phodrang Dzongkhag.

Table 4.16 shows tree density by different diameter class. The tree density was greatest in the Height Class 5-10 m and 10-15 m and smallest in Height Class greater than 40 m. Figure 4.9 shows that more than two third of tree are less than 15 m in Height in Forest.

Table 4.16 Tree density by Height Class

Height Class (m)	Tree Count (No. ha^{-1})	MoE (%)	Lower Limit	Upper Limit
<5	11	11	10	12
5-10	127	5	122	133
10-15	127	4	121	132
15-20	60	5	58	63
20-25	29	6	28	31

25-30	13	7	12	14
30-35	5	11	5	6
35-40	2	16	2	3
>= 40	1	25	1	2

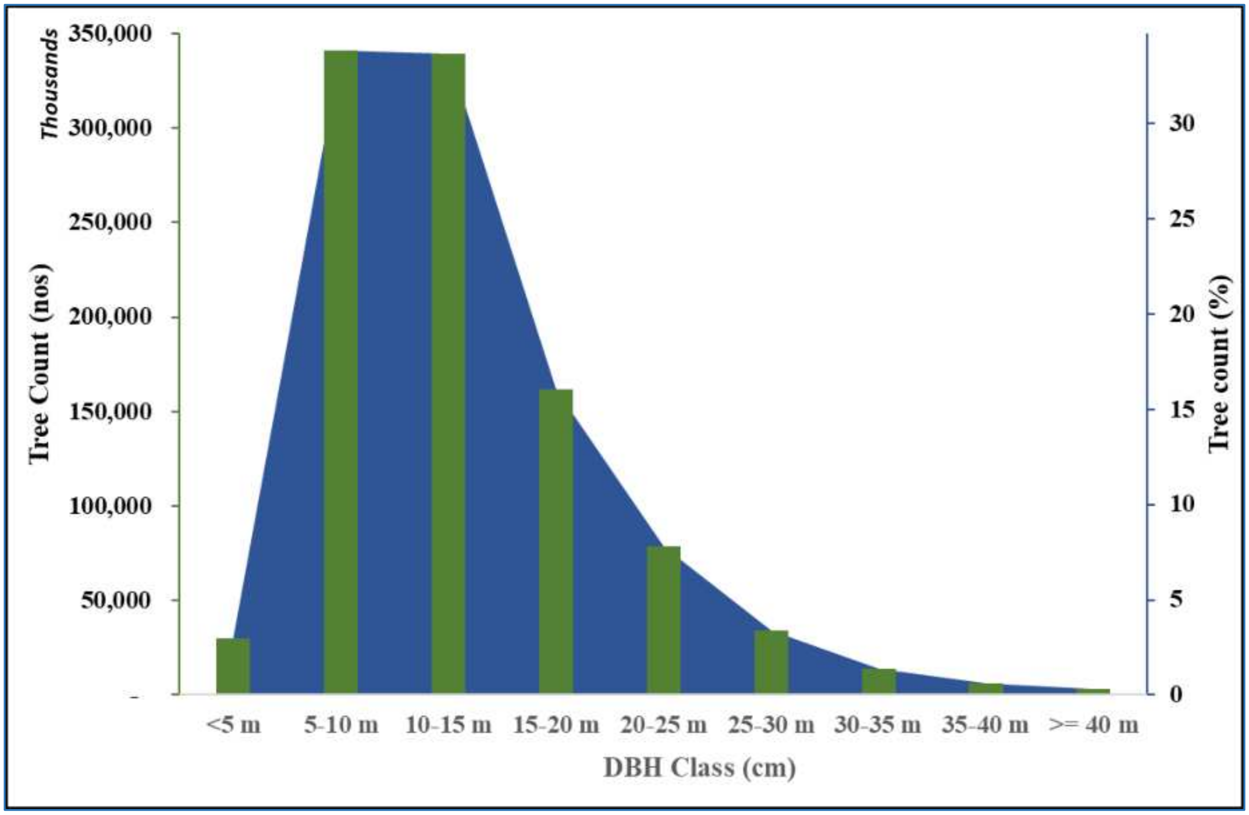


Figure 4.9: Comparison of tree count and proportion of total trees by height class

4.2.7 Stem Density by Species

NFI recorded more than 710 species of trees during the field work. Tree counts are estimated only for a selected number of species which has species specific volume equations and other species are clubbed as "*Other*s". Table 4.17 shows the total tree count by species. *Rhododendron* spp. is estimated to have greatest number of total tree count with about 126 million trees followed by *Quercus* spp. with 81 million trees.

Table 4.17 Total tree count by Species

Species Name	Tree Count (No.)	MoE (%)	Lower Limit	Upper Limit
Abies densa	55,507,706	16	46,619,890	64,395,522
Acer spp.	36,113,379	13	31,582,029	40,644,728
Ailanthus integrifolia	741,548	95	39,853	1,443,243
Alnus spp.	7,643,647	27	5,610,004	9,677,289
Aphanamixis polystachya	2,492,741	31	1,711,414	3,274,069

Beilschmiedia spp.	8,904,278	22	6,969,865	10,838,691
Betula spp.	21,014,324	19	17,092,009	24,936,639
Bombax ceiba	370,774	52	178,907	562,641
Castanopsis spp.	32,987,469	18	27,173,974	38,800,965
Cupressus spp.	530,492	111	-58,555	1,119,539
Duabanga grandiflora	1,346,194	50	674,604	2,017,785
Engelhardtia spicata	9,953,853	24	7,545,229	12,362,478
Exbucklandia populnea	2,293,094	41	1,359,765	3,226,423
Juglans regia	867,041	49	444,758	1,289,323
Juniperus spp.	18,886,652	30	13,304,083	24,469,222
Larix griffithii	1,009,646	53	471,983	1,547,309
Magnolia spp.	5,527,383	28	3,989,671	7,065,096
Persea spp.	38,258,163	13	33,214,489	43,301,837
Phoebe goalparensis	804,294	88	97,297	1,511,292
Picea spinulosa	8,276,814	33	5,557,593	10,996,036
Pinus roxburghii	15,469,828	32	10,525,739	20,413,918
Pinus wallichiana	33,078,737	29	23,572,370	42,585,103
Quercus spp.	81,410,542	11	72,152,325	90,668,758
Rhododendron spp.	125,823,551	11	111,838,973	139,808,130
Schima wallichii	15,458,420	22	12,071,111	18,845,729
Sterculia villosa	1,106,618	42	637,305	1,575,930
Symplocos spp.	41,555,199	14	35,665,416	47,444,981
Taxus baccata	2,179,010	45	1,203,738	3,154,282
Terminalia myriocarpa	741,548	38	460,000	1,023,095
Tetrameles nudiflora	536,196	45	296,511	775,881
Tsuga dumosa	12,691,876	27	9,210,074	16,173,678
Others	424,342,180	5	403,346,481	445,337,879

4.3 Discussion

Stem density is important information for forest management as it helps in planning silvicultural activities in the forests (Das et al., 2021). Tree abundance is strongly linked with ecosystem functioning (Madrigal-González et al., 2023) and a good understanding of the stem density shall help in the management of forest stands through the prescription of appropriate management prescription; thinning, harvesting operation, restocking and other stand management activities to enhance the health and productivity of the forests.

Madrigal-González et al., (2023) reported a global tree density range of 500- 800 tree ha^{-1} for highly productive sites where all trees above 5 cm are considered as trees. These includes trees and sapling reported for NFI in Bhutan. Therefore, the combined stem density of 572 (377± 10 trees ha^{-1} and 195 ± 8 saplings ha^{-1}) is within the global range reported in the study. Similar tree and sapling densities of 300.25 trees ha^{-1} and 205 sapling ha^{-1} (Das et al., 2021), 340-650 trees ha^{-1} and 400 – 800 saplings ha^{-1} (Ballabha et al., 2013) are reported in Western Himalayas of India while a stem density of 117.5 to 181 trees ha^{-1} is reported in eastern Himalayas of Arunachal Pradesh of India (Dash et al., 2021).

The tree density in Bhutan has increased from 280 ± 8 trees ha^{-1} reported in the first NFI (FRMD, 2016b) to 377± 6 in 2021. This is due to the increase in the number of young and smaller trees of smaller DBH evident from Table 4.15 and Figure 4.8, wherein the tree density in the lower diameter class of 10-20 cm has doubled and almost doubled in DBH class 20-30 cm, while, tree density in larger diameter class decreased or only increased marginally. Further, a similar increase in tree density in the lower diameter class can be expected in the future with favorable sapling density (
Table 4.3) recorded. The tree and DBH patterns form a "L" shaped distribution with a greater number of trees in lower diameter class and fewer trees in the higher diameter class. This can be inferred to as a young forest and similar distribution was also observed in the Old *Abies pindrow* forest in western Himalayas (Das et al., 2021), sub-tropical forest of Garhwal region in India (Ballabha et al., 2013) and tropical evergreen forest in Arunachal Pradesh, Eastern Himalayas (Dash et al., 2021). The dwindling number of larger trees would be concern for forest management to promote the growth and development of trees in the lower DBH class.

The tree density has increased in all categories of Forest Types compared to the 1st NFI (FRMD, 2016b) and though it has also increased in Chir Pine and Blue Pine Forests compared to PIS, the tree density has decreased in other Forest Types. Tree density has also increased by Dzongkhag, DBH and Height Class and Elevation. The increase in tree density in all categories may be attributed to an increase in tree density in lower DBH with the sapling recorded previously growing into trees.

BASAL AREA

5 BASAL AREA

5.1 Introduction

The Basal area of a tree is the cross-sectional area of a tree and is used to estimate the stand basal area and the total basal area in the country. West, 2009 defined the stand basal area as "*the tree cross-sectional area at breast height summed over all the trees in a stand and expressed per unit ground area"*. The stand basal area is indicative of the number and size of the tree present in the stand. Basal area and diameter measurements are also key to estimating the growth of individual trees. Growth in terms of basal area increment and volume increment is estimated and discussed in detail in the chapter BASAL AREA INCREMENT. Taking the basal area estimated herein as a reference, the basal area of the individual tree before five years is estimated from the increment data estimated from the tree core collected as part of the NFI.

For the purpose of the NFI, the basal area of an individual tree is estimated using the diameter measured at breast height (1.37 m) in the plot of 0.05 ha (12.62 m radius). A similar approach is adopted for inventory of Forest Management Units (FMU) in Bhutan while the basal area in Local Forest Management Areas (LFMA) and Community Forest (CF) Management Group is estimated using point sampling method (DoFPS, 2021c).

Basal area of individual trees is estimated using the DBH of each tree in a plot and the sum of the basal area of all trees in the plot provides you with the stand basal area (Equation 5.1). This is further extrapolated to per hectare level by dividing the stand basal area by the plot area or by multiplying by the plot expansion factor $A_{exf.}$

$$\mathrm{BA} = \pi * (\frac{d}{2 * 100})^\wedge 2$$

Equation 5.1

$$\mathrm{BA\ per\ ha} = \mathrm{BA} / \mathrm{A_p}$$

Equation 5.2

Where,

BA is the basal area of the tree;
d is the diameter in cm; and
A_p is the plot area.

The stand basal area for each plot is then averaged out for each cluster plot by taking into account all accessible forest plots in the cluster to estimate the basal area per ha for each cluster. The basal area per ha for the CP is then used to estimate the mean basal area and total basal area of the country. The variance for the basal area and the area is estimated following the methodologies discussed in 2.2.3 Descriptive Statistics and Summaries under Chapter 2 METHODOLOGY.

5.2 Basal Area by Different Categories

Basal Area is estimated for different categories starting with the basal area in Forest and Non-Forest. The basal area in Forest is then used to estimate the basal area in different categories as described hereon.

5.2.1 Basal Area by Land Area

The total basal area in Bhutan's Forest is estimated to be 87,635,332.76 m^2 with an average basal area of 32.74 m^2 per hectare. The total and basal area per ha in Forest and Non-Forest are shown in Table 5.1 and Table 5.2.

Table 5.1 Total basal area by Forest and Non-Forest

Land Type	Basal area (m^2)	MoE (%)	Upper Limit	Lower Limit
Forest	87,635,332.76	3.64	90,822,722.79	84,447,942.73
Non-Forest	4,243,930.77	25.79	5,338,271.94	3,149,589.60

Table 5.2 Basal area per ha by Forest and Non-Forest

Land Type	Basal area (m^2 ha^{-1})	MoE (%)	Lower Limit	Upper Limit
Forest	32.74	1.02	31.72	33.76
Non-Forest	1.59	0.41	1.18	1.99

5.2.2 Basal Area by Dzongkhag

Table 5.3 and Figure 5.1 shows the total basal area and the basal area percentage in each Dzongkhag. The basal area ranges from 23.43 m^2 ha^{-1} to 41.57 m^2 ha^{-1}. Bumthang Dzongkhag has the greatest basal area per ha (41.57 m^2 ha^{-1}) and Pemagatshel the smallest (23.43 m^2 ha^{-1}).

Table 5.3 Basal area per ha by Dzongkhag

Dzongkhag	Basal area (m^2 ha^{-1})	MoE (%)	Lower Limit	Upper Limit
Bumthang	41.57	11.26	46.26	36.89
Chhukha	28.43	13.85	32.36	24.49
Dagana	33.32	11.23	37.06	29.58
Gasa	26.75	24.15	33.21	20.29
Haa	39.54	14.94	45.45	33.63
Lhuentse	37.27	15.21	42.94	31.60
Mongar	34.35	12.58	38.67	30.03
Paro	32.36	19.21	38.57	26.14
Pemagatshel	23.43	13.87	26.68	20.18

Punakha	35.18	11.48	39.22	31.14
Samdrup Jongkhar	23.99	12.75	27.05	20.93
Samtse	23.76	14.85	27.29	20.24
Sarpang	29.09	12.07	32.60	25.58
Thimphu	36.65	18.14	43.30	30.00
Trashi Yangtse	39.39	15.26	45.40	33.38
Trashigang	34.70	12.43	39.02	30.39
Trongsa	38.86	14.39	44.45	33.27
Tsirang	25.15	17.97	29.67	20.63
Wangdue Phodrang	35.19	9.79	38.64	31.75
Zhemgang	31.78	8.32	34.43	29.14

Wangdue Phodrang Dzongkhag has the greatest total estimate for the basal area with 9.11 million m^2 contributing to 10.32 % of the total basal area estimate of Bhutan's Forest. Zhemgang follows closely with 7.09 million m^2 contributing 8.03 % while Tsirang has the smallest estimate of 1.37 million m^2 which is 1.55 % of the total basal area. The total basal area estimate for Gasa is 1.75 million m^2 contributing about 1.98 % of the total basal area of Bhutan's forest.

As is evident for the greatest and smallest estimates of basal area, the total estimate is directly related to the total forest area of each Dzongkhag irrespective of the size of the Dzongkhag. The Dzongkhag-wise estimate and the percentage of the total basal area are shown in Figure 5.1.

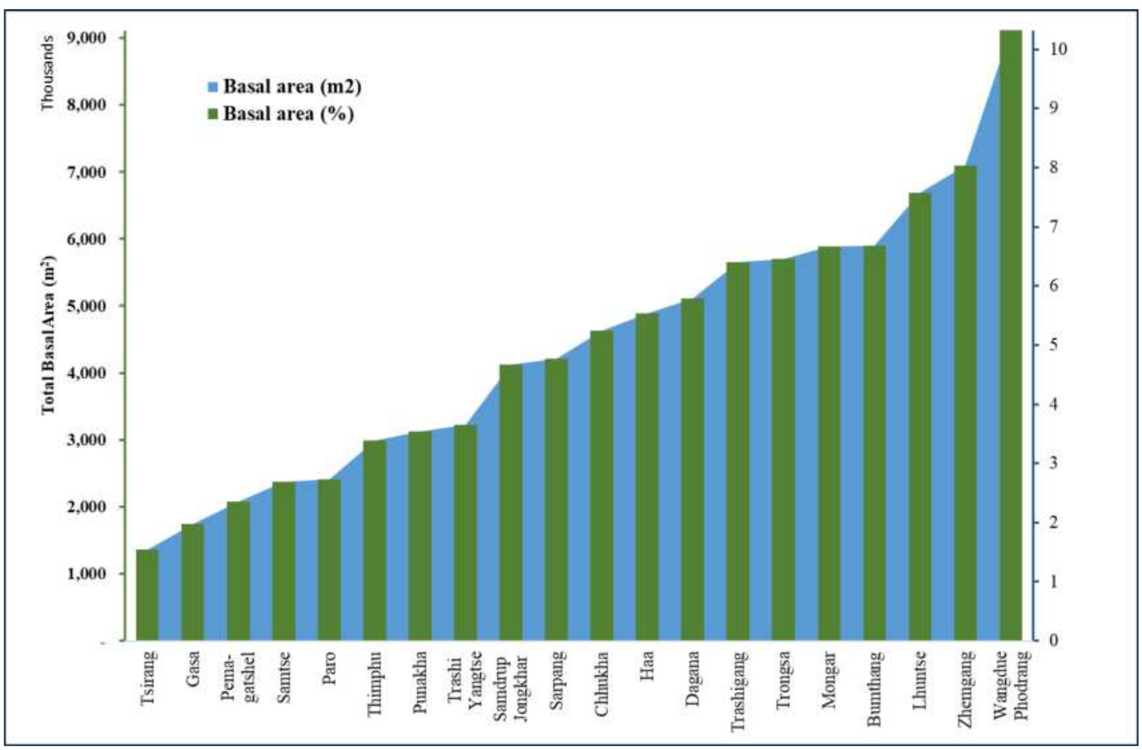


Figure 5.1 Total basal area and basal area (%) by Dzongkhag

5.2.3 Basal Area by Forest Type

Table 5.4 and Table 5.5 show the total basal area and basal area per ha by Forest Class. Broadleaved Forest has greater total basal area (58.27 million m^2) than Coniferous Forest (29.53 million m^2). However, Coniferous Forest has greater basal area per ha (34.46 m^2 ha^{-1}) compared to Broadleaved Forest (32.02 m^2 ha^{-1}).

Table 5.4 Total basal area by Forest Class

Forest Class	Basal Area (m^2)	MoE (%)	Upper Limit	Lower Limit
Broadleaved Forest	58,273,278.01	4.19	60,717,346.34	55,829,209.68
Coniferous Forest	29,530,695.64	6.56	31,468,070.11	27,593,321.17

Table 5.5 Basal area per ha by Forest Class

Forest Class	Basal Area (m^2 ha^{-1})	MoE (%)	Upper Limit	Lower Limit
Broadleaved Forest	32.02	3.57	33.17	30.88
Coniferous Forest	34.46	6.18	36.59	32.33

Though the total basal area of Broadleaved Forest accounts for around 66 % of the Forest basal area compared to the Coniferous Forest with 34 %, it does not differ significantly on the basal area per ha. The graphical representation of the same is presented in Figure 5.2.

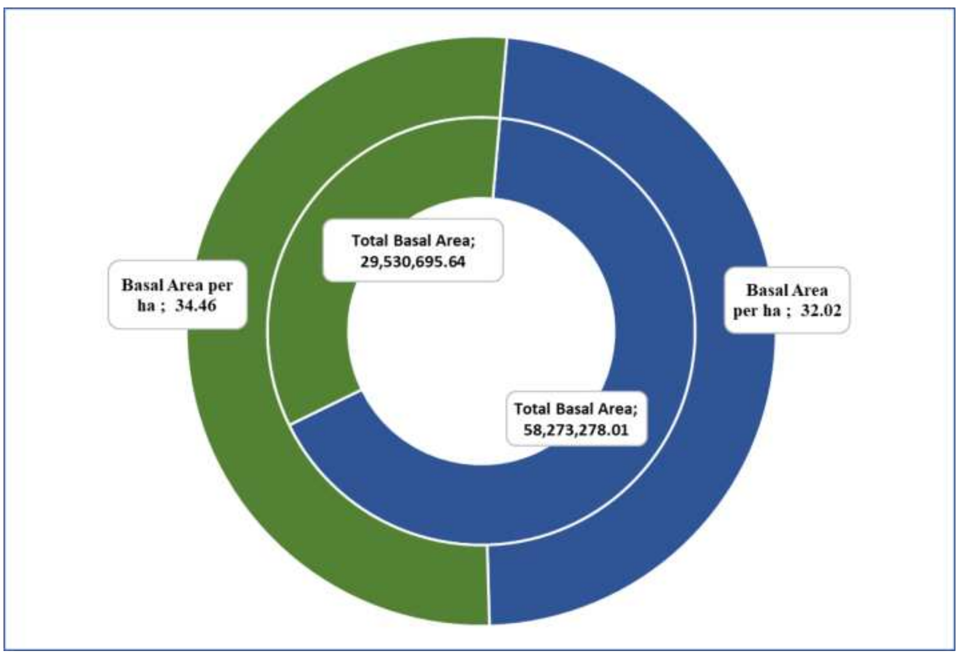


Figure 5.2 Basal area per ha and total basal area by forest class

Further segregation of the Forest Class shows that Hemlock Forest has the greatest basal area per ha (46.51 m^2 ha^{-1}) while Chir Pine Forest has the smallest basal area per ha (15.14 m^2 ha^{-1}). Spruce has basal area of 36.95 m^2 ha^{-1} which is comparable to the Evergreen Oak Forest (38.07 m^2 ha^{-1}), the greatest amongst the Broadleaved Forest.

Table 5.6 Basal area per ha by forest type

Forest Type	Basal area per ha (m^2)	MoE (%)	Lower Limit	Upper Limit
Blue Pine Forest	23.14	16.27	19.38	26.91
Chir Pine Forest	15.14	17.81	12.44	17.84
Cool Broadleaved Forest	42.89	4.48	40.97	44.82
Evergreen Oak Forest	38.07	23.71	29.04	47.10
Fir Forest	44.47	6.40	41.62	47.31
Hemlock Forest	46.51	14.76	39.64	53.37
Juniper Rhododendron Forest	15.34	29.64	10.80	19.89
Spruce Forest	36.95	20.15	29.50	44.39
Subtropical Forest	20.08	6.88	18.70	21.46
Warm Broadleaved Forest	27.67	5.52	26.14	29.20

Figure 5.3 shows the total basal area distribution among the different Forest Types. Cool Broadleaved Forest dominates the forest stand (32.35 million m^2) and constitutes around 35 % of the total basal area of the Forest. Fir Forest has the second greatest basal area with an estimate of 19.24 million m^2 (21 %). Amongst the Broadleaved Forest, Warm Broadleaved has the greatest total basal area with 18.5 million m^2 (20.32 % of the total basal area). Juniper Rhododendron Forest and Chir Pine Forest has the smallest total basal area with approximately 1.1 million m^2.

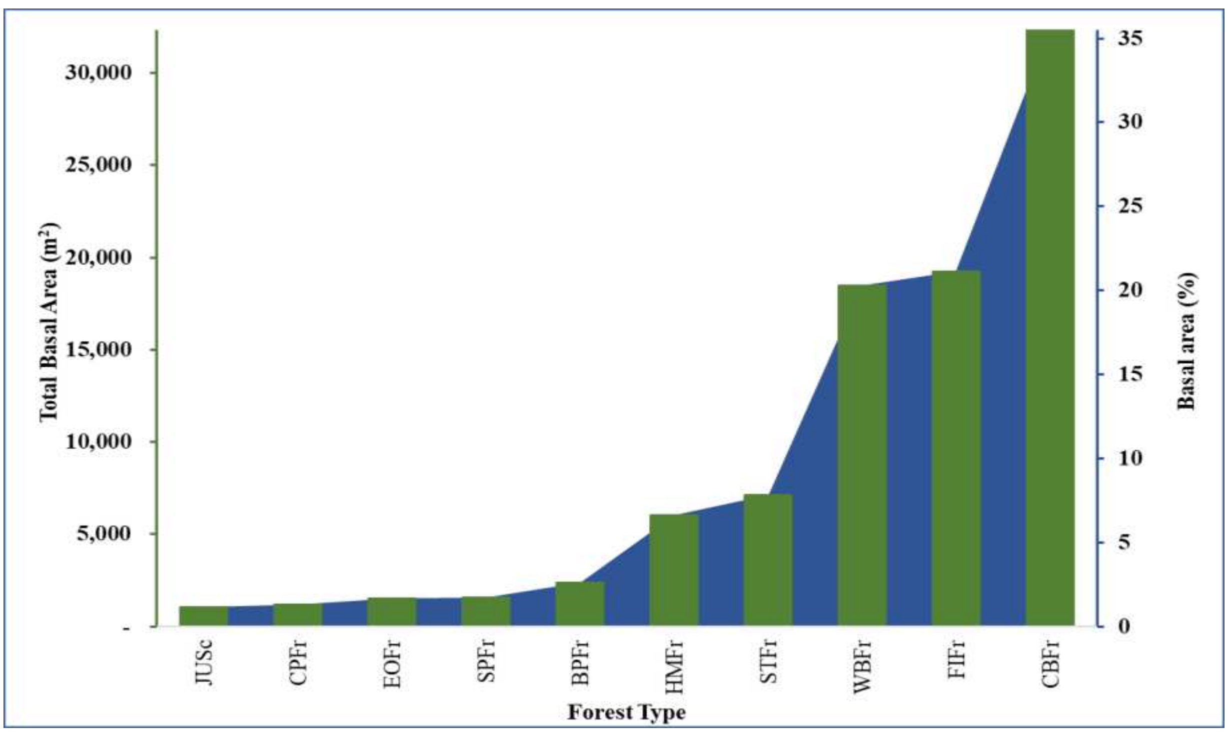


Figure 5.3 Total basal area by Forest Type

5.2.4 Basal Area by Elevation

Table 5.7 shows the basal area per ha by Elevation. Basal area density is greatest in the elevation range of 2000-3000 *m.a.s.l* (41.70 m^2 ha^{-1}). The elevation range 0-1000 *m.a.s.l* has a basal area of 19.20 m^2 ha^{-1}, increasing gradually to peak at 2000-3000 *m.a.s.l* and 3000-4000 *m.a.s.l*. Basal area is the smallest in the elevation range >=4000 *m.a.s.l* (11.82 m^2 ha^{-1}).

Table 5.7 Basal area per ha by Elevation

Elevation	Basal Area (m^2 ha^{-1})	MoE (%)	Lower Limit	Upper Limit
0-1000	19.20	7.07	17.85	20.56
1000-2000	25.93	5.19	24.58	27.27
2000-3000	41.70	4.42	39.86	43.55
3000-4000	40.32	5.96	37.92	42.72
>=4000	11.82	45.19	6.48	17.16

The total basal area shows a similar trend to the basal area per ha and is shown in Figure 5.4. Forty percent of the total basal area is found in the 2000-3000 *m.a.s.l* while the least is found in the elevation >=4000 which represents only one percentage of the total basal area.

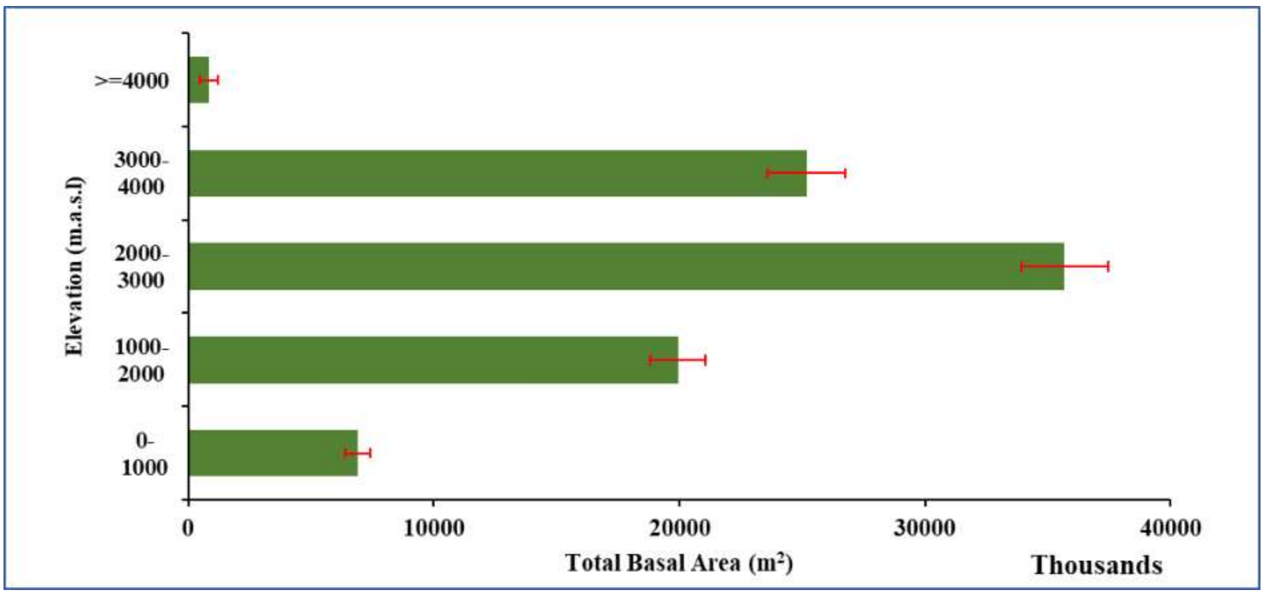


Figure 5.4 Total basal area by Elevation

5.2.5 Basal Area by Diameter Class

Individual trees are grouped into DBH and Height Class depending on the DBH and total height of the individual tree as discussed in section 2.2.2.3 DBH Class and 2.2.2.4 Height Class under Chapter 2 METHODOLOGY. Table 5.8 show the basal area per ha by DBH class. Basal area per ha is greatest in the DBH class of =>100, with 5.13 m^2 ha^{-1}. Trees with DBH Class 10-20 and 20-

30 have a total basal area per ha of 6.87 m^2 ha^{-1} representing 21 % of the total basal area per ha of Bhutan's Forest.

Table 5.8 Basal area per ha by DBH class

DBH Class	Basal area (m^2 ha^{-1})	MoE (%)	Lower Limit	Upper Limit
10-20	3.17	3.74	3.05	3.29
20-30	3.70	3.61	3.57	3.83
30-40	3.91	3.68	3.77	4.05
40-50	3.65	4.29	3.49	3.80
50-60	3.36	5.33	3.18	3.54
60-70	3.01	6.10	2.82	3.19
70-80	2.58	7.11	2.39	2.76
80-90	2.42	8.27	2.22	2.62
90-100	1.82	10.06	1.64	2.00
=>100	5.13	10.02	4.62	5.65

The total basal area in the DBH class 10-20 is 8.49 million m^2. The total basal area increases gradually till the DBH class of 30-40 and decreases thereafter till the 90-100 DBH class. The greatest basal area is represented in the DBH class =>100 cm with 13.73 million m^2 which is about 15.67 % of the total basal area while DBH 90-100 has the smallest total basal area (4.87 million m^2) representing 5.56 % of the total basal area.

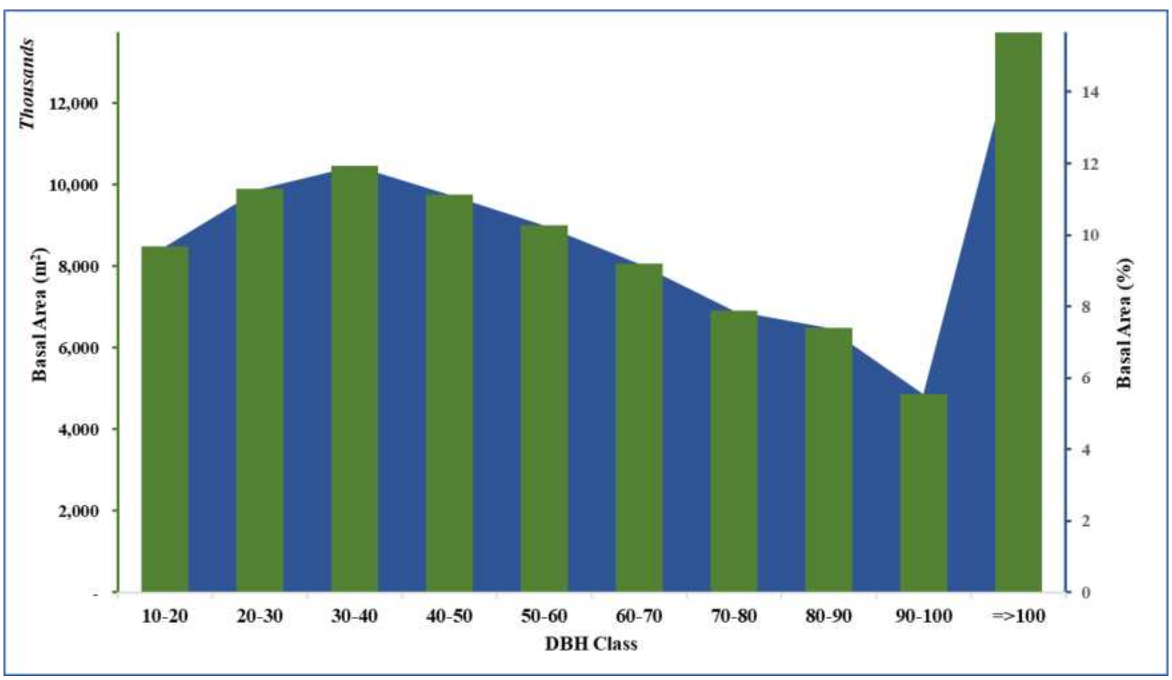


Figure 5.5 Total basal area by DBH Class

5.2.6 Basal Area by Height Class

Table 5.9 shows the basal area per ha estimate for different height classes and the total basal area by Height Class is shown in Figure 5.6. The smallest basal area is estimated to be below 5 m (basal area per ha of 0.28 m^2 ha^{-1} and total basal area of 0.76 million m^2) which increases gradually till it reaches the peak at the Height Class of 15-20 m (7.13 m^2 ha^{-1} and 19.1 million m^2) and then decreases with the increase in the Height Class. Figure 5.6 shows an almost normal distribution with its peak at 15-20 Height Class.

Table 5.9 Basal area per ha by Height Class

Height Class	Basal area (m^2 ha^{-1})	MoE (%)	Lower Limit	Upper Limit
<5	0.28	13.86	0.32	0.24
5-10	3.52	5.20	3.71	3.34
10-15	6.62	4.55	6.92	6.32
15-20	7.13	4.80	7.47	6.79
20-25	6.56	6.27	6.97	6.15
25-30	4.46	8.23	4.83	4.09
30-35	2.27	11.79	2.54	2.00
35-40	1.09	16.76	1.27	0.91
=>40	0.81	26.26	1.02	0.59

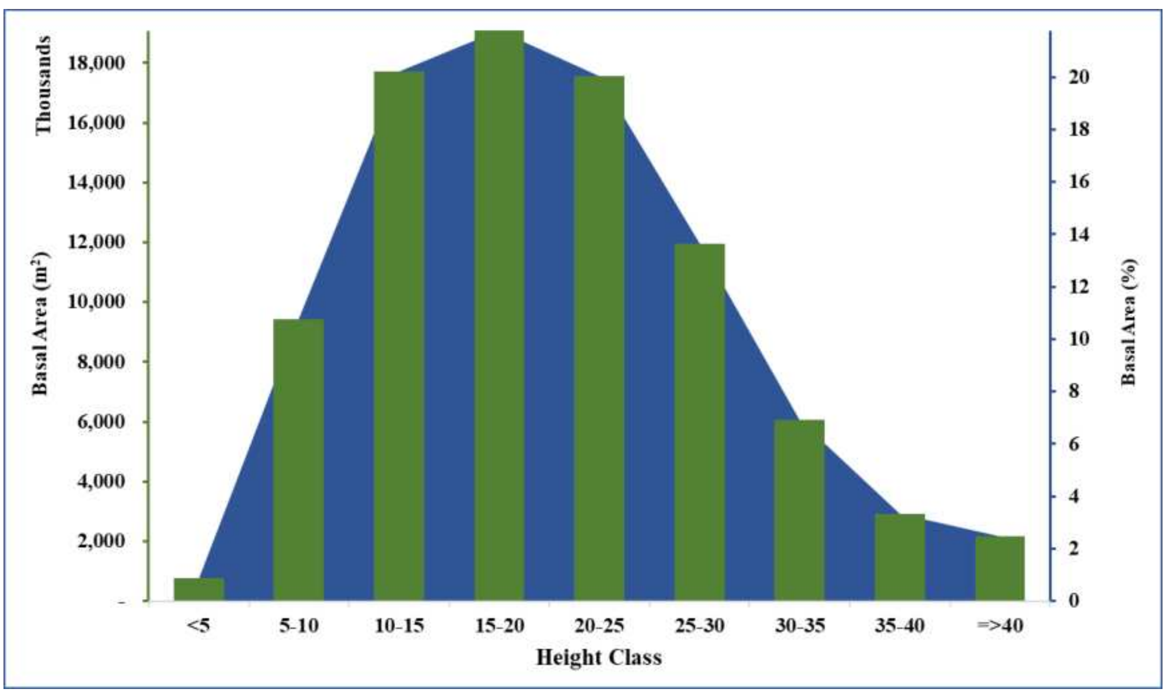


Figure 5.6 Total basal area by Height Class

5.2.7 Basal Area by Species

Table 5.10 shows the total basal area estimate for 32 species and the rest are clubbed as "*Other*". The total basal area of the 32 species is estimated to 60.42 million m^2, which represent about 69 % of the total basal area of Bhutan's Forest. Fir (*Abies densa*) has the greatest basal area of 12.96 million m^2 which represents 14.78 % of the total basal area followed by oak species (*Quercus spp.)* which represents 13.04 % of the total basal area with a basal area of 11.43 million m^2. Blue Pine (*Pinus wallichiana*), *Cupresssus* spp. and walnut (*Juglans regia*) account for 2.65 %, 0.19 % and 0.13 % respectively of the total basal area of the Forests.

Table 5.10 Total basal area by Species

Species	Basal Area (m^2)	MoE (%)	Lower Limit	Upper Limit
Abies densa	12,956,281.93	14.68	11,053,656.75	14,858,907.11
Acer spp.	3,210,789.32	12.76	2,801,239.04	3,620,339.60
Ailanthus integrifolia	85,322.05	75.11	21,240.28	149,403.83
Alnus spp.	960,881.68	25.00	720,646.77	1,201,116.60
Aphanamixis polystachya	153,242.14	41.41	89,791.27	216,693.01
Beilschmiedia spp.	849,334.93	24.47	641,523.34	1,057,146.52
Betula spp.	1,739,367.49	16.34	1,455,225.87	2,023,509.12
Bombax ceiba	96,354.27	74.88	24,206.25	168,502.30
Castanopsis spp.	3,798,590.43	15.81	3,198,064.78	4,399,116.08
Cupressus spp.	170,380.16	157.37	(97,755.16)	438,515.48
Duabanga grandiflora	326,475.84	41.42	191,238.17	461,713.50
Engelhardia spicata	788,925.39	24.26	597,561.30	980,289.49
Exbucklandia populnea	393,709.62	55.04	176,999.82	610,419.41
Juglans regia	109,585.13	52.53	52,020.24	167,150.01
Juniperus spp.	1,602,026.40	33.10	1,071,679.23	2,132,373.57
Larix griffithii	100,128.70	62.16	37,887.78	162,369.63
Magnolia spp.	849,628.93	25.49	633,071.15	1,066,186.70
Persea spp.	3,935,386.10	14.66	3,358,389.22	4,512,382.99
Phoebe goalparensis	95,247.47	72.34	26,346.45	164,148.49
Picea spinulosa	1,186,802.70	33.99	783,457.94	1,590,147.46
Pinus roxburghii	1,161,411.53	30.10	811,855.13	1,510,967.93
Pinus wallichiana	2,325,780.17	25.33	1,736,716.21	2,914,844.14
Quercus spp.	11,427,886.60	10.96	10,175,630.33	12,680,142.88
Rhododendron spp.	4,989,413.58	11.41	4,420,054.72	5,558,772.44
Schima wallichii	1,131,778.69	21.86	884,320.86	1,379,236.51
Sterculia villosa	141,877.94	45.21	77,731.69	206,024.18
Symplocos spp.	1,312,682.57	15.44	1,109,983.32	1,515,381.81
Taxus baccata	274,420.15	39.76	165,315.78	383,524.53

Terminalia myriocarpa	170,369.72	61.86	64,982.22	275,757.23
Tetrameles nudiflora	246,743.65	60.46	97,570.71	395,916.60
Toona ciliata	322,407.33	44.18	179,972.41	464,842.25
Tsuga dumosa	3,501,960.40	23.84	2,667,195.00	4,336,725.80
Other	27,220,139.73	5.63	25,687,930.80	28,752,348.67

5.2.8 Discussion

The basal area per ha of Bhutan's Forest is estimated to be 32.74±1.02 m^2 ha^{-1}. The basal area per ha estimate reported is lower than the basal area per ha estimated for Forest (40 m^2 ha^{-1}) in the 1^{st} NFI. Similarly, Tenzin & Hasenauer (2016) reported a basal area of 9.63 ±12.73 and 37.89±23.9 in semi-disturbed and natural broadleaved forest respectively of Bhutan (Dagana). Further, Mehra et al., (2023) reported a tree basal area ranging between 24.05 to 35.15 m^2 ha^{-1} in four different forest types in Western Himalaya, wherein a basal area per ha of 25.15 m^2 ha^{-1} and 33.15 m^2 ha^{-1} was recorded for Chir Pine and Oak Forest respectively. The basal area estimates for Bhutan's Forest fall within the range of the basal area reported (9.63 m^2 ha^{-1} to 40 m^2 ha^{-1}) in the region and these is further discussed under different categories.

The per ha estimate of the basal area is smaller in Broadleaved Forest compared to the Coniferous Forest. The average basal area per ha for Broadleaved Forest in general is estimated to be 32.02±1.14 m^2 ha^{-1}, lower than the basal area of 32.74±1.02 m^2 ha^{-1} recorded for Bhutan's Forest. However, Broadleaved Forest constitutes 66 % of the total basal area (58.27 million m^2) compared to 29.53 million m^2 recorded for Coniferous Forest. This is because of the larger extent and stem density of the Broadleaved Forest in comparison to the Coniferous Forest. The Broadleaved Forest constitutes about 67.99 % of the total forest area and 69.27 % of the total tree count in the Forest.

Cool Broadleaved Forest has the smallest basal area per ha of 15.14±2.70 m^2 ha^{-1} while the greatest basal area per ha is observed for Fir Forest at 44.47±2.85 m^2 ha^{-1}. Further, the Cool Broadleaved Forest, which forms the greatest forest type in Bhutan with an estimated 28 % of the total forest area covers only 1.3 % of the total basal area of Bhutan's forest. One of the main reasons, being the smaller sizes of trees in the Cool Broadleaved Forest. The Cool Broadleaved Forest has a tree count of 417 trees per ha, from which about 189 (45 % of the tree count per ha) is found in the 10-20 DBH class. Generally, 51 % of the total trees are found in the 10-20 DBH class with an average tree count of 191 trees while almost 72 % of the total trees have a DBH below 30 cm and constitutes the 10-20 and 20-30 DBH classes. Further, the NFI estimates shows that the greatest basal area is found in the 30-40 DBH class and Height class of 15-20.

Basal area per ha in the Dzongkhag ranges from 23.43±3.25 m^2 ha^{-1} for Pemagatshel to 41.57±4.68 m^2 ha^{-1} for Bumthang Dzongkhag. Basal area was greater in Dzongkhags such as Bumthang, Haa, Trashi Yangtse and Trongsa, which are predominantly Coniferous Forest and has recorded a basal area density of more than 38 m^2 ha^{-1} while Dzongkhag such as Pemagatshel, Samtse, Samdrup Jongkhar and Tsirang Dzongkhag has recorded basal area density of less than equal to 25 m^2 ha^{-1}. Overall, there is a decrease in the total basal area from 107.9 million m^2 in the 1st NFI to the current estimate of 87.64 million m^2.

A better understanding of the basal area and the basal area estimate is an effective tool for stand management. This shall help in understanding the requirement of thinning, regeneration and gap filling and other stand management activities, to improve growth and stand health.

GROWING STOCK

6 GROWING STOCK

6.1 Introduction

Growing stock refers to the standing volume of all living trees in a given area of Forest (FRMD, 2016b). It is the most important information measured by forest inventories for informed policy decision-making and management planning (Gschwantner et al., 2022; Huang et al., 2022). Therefore, assessment and monitoring of the growing stock is important for the sustainable management of the forest.

This chapter provides a brief discussion on the growing stock estimation methods and estimates of volume by different categories. The volume of each individual trees is estimated using equations developed during the PIS of Forest Resources of Bhutan (1974-1980). Two types of volume equations were developed for important species identified during the PIS; (i) General Volume equation which uses both DBH and Height as predictor variable; (ii) Local Volume equation which uses only DBH as the predictor variable. In addition, a common equation was developed for both criteria. These equations were developed for three regions; North Western, Central & Eastern, and Southern Bhutan.

For the NFI, the general volume equation for the 28 species was used for volume estimation in addition to the equation for the "*rest of the species*" *for* all other species. The list of volume equations is provided in the ***Annexure I of this report.*** In situation where species specific volume model predicted the negative volume for smaller diameter trees, the volume of the tree was estimated using the equation for the "*rest of the species*" for that region[2]. The volume of individual tree is multiplied by area expansion factor to estimate per ha volume and summed together as plot level per ha volume. The plot volume is averaged to find the mean volume for each cluster plot, which was used for estimating per ha volume for any forest or any domain of interest; The mean volume of the strata/stratum is prorated by multiplying the volume per hectare for that domain with an estimated area of same domain or stratum (Gregoire & Valentine, 2007) . The estimation method is similar and discussed in detail in Chapter 3 FOREST COVER and Chapter 4 STEM DENSITY.

6.2 Volume by Different Categories

This chapter provides the estimate of the volume per ha and total volume by National level, Dzongkhag, Forest Type, Elevation and Species and are discussed herein.

6.2.1 Volume by Land Area

The total growing stock of Forest is 759 million m^3 of wood in standing volume with a mean volume of 283.65 m^3 ha^{-1}. Non-Forest land also contributes about 13.7 million m^3 to the growing

[2] The volume predicted by the common volume equation and species-specific volume equation for selected larges trees were compared. The volume predicted by the common volume table is not significantly different from the species-specific volume.

stock of the country. Table 6.1 and Table 6.2 shows the total volume and volume per ha in Forest and Non-Forest respectively.

Table 6.1 Total volume in Forest and Non-Forest

Land Type	Volume (m^3)	MoE%	Lower Limit	Upper Limit
Forest	759,206,199.86	4.29	726,624,632.93	791,787,766.79
Non-Forest	13,703,619.18	34.46	8,982,030.52	18,425,207.84

Table 6.2 Volume per ha in Forest and Non-Forest

Land Type	Volume (m^3 ha^{-1})	MoE (%)	Lower Limit	Upper Limit
Forest	283.65	3.86	272.69	294.61
Non-Forest	11.78	34.4	7.73	15.84

6.2.2 Volume by Dzongkhag

Table 6.3 shows the volume per ha by Dzongkhag and Figure 6.1 shows the proportion of total volume by Dzongkhag. The volume per ha ranges from 165.07 m^3 ha^{-1} to 278.63 m^3 ha^{-1}. The greatest Volume per ha is found in Bumthang Dzongkhag (378.63 m^3 ha^{-1}) and the smallest in Pemagatshel Dzongkhag (165.07 m^3 ha^{-1}). The average volume in Bumthang, Haa, Lhuentse, Paro, Mongar, Punakha, Thimphu, Trashigang, Trashi Yangtse, Trongsa and Wangdue Phodrang Dzongkhags are greater than the National average while average volume in other Dzongkhags are smaller than the National level average volume in Forest (283.65 m^3 ha^{-1}).

Table 6.3 Volume per ha by Dzongkhag

Dzongkhag	Volume (m^3 ha^{-1})	MoE (%)	Lower Limit	Upper Limit
Bumthang	378.63	13.40	327.89	429.36
Chhukha	239.35	16.15	200.69	278.02
Dagana	270.55	13.15	234.96	306.14
Gasa	231.24	29.53	162.95	299.54
Haa	320.20	18.38	261.34	379.05
Lhuentse	350.59	18.96	284.10	417.07
Mongar	304.83	13.96	262.26	347.40
Paro	337.54	25.49	251.51	423.57
Pemagatshel	165.07	17.20	136.67	193.46
Punakha	292.55	15.66	246.73	338.37
Samdrup Jongkhar	217.19	16.42	181.53	252.86
Samtse	217.88	18.32	177.98	257.79
Sarpang	250.39	14.66	213.68	287.10
Thimphu	353.33	21.53	277.26	429.41
Trashigang	288.78	14.45	247.06	330.50
Trashi Yangtse	348.62	19.71	279.92	417.31

Trongsa	329.96	16.73	274.77	385.15
Tsirang	188.71	22.06	147.07	230.34
Wangdue Phodrang	298.61	13.10	259.48	337.73
Zhemgang	269.18	11.44	238.39	299.98

Tsirang Dzongkhag contributes the least to the total forest growing stock with 10.26 million m^3 of standing volume which constitutes about 1.34 % while Wangdue Phodrang Dzongkhag contributes the most with 7.73 million m^3 of standing volume (10.10%) closely followed by Lhuentse Dzongkhag with 6.29 million m^3 (8.22%). Seven Dzongkhags of Wangdue Phodrang, Lhuentse, Zhemgang, Bumthang, Mongar, Trongsa and Trashigang contributes more than 50% of the total forest growing stock in the country.

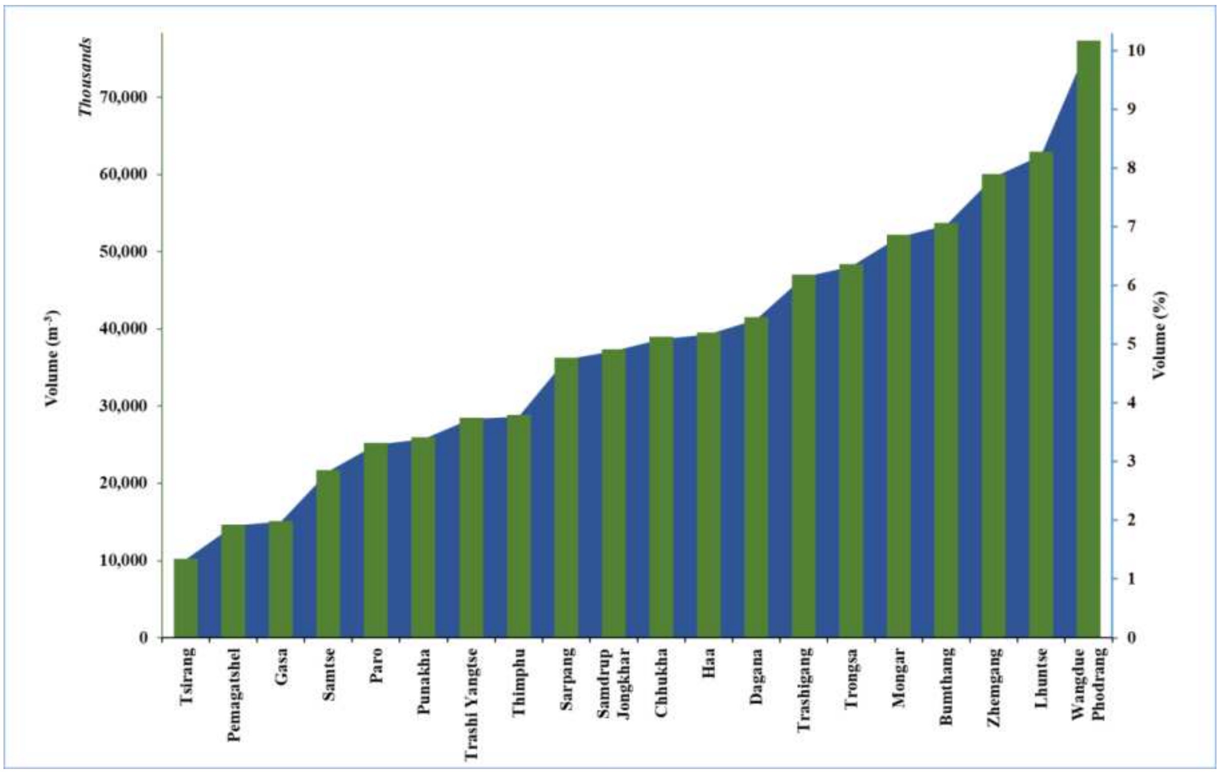


Figure 6.1 Total Volume by Dzongkhag

6.2.3 Volume by Forest Type

Table 6.4 and Table 6.5

Table 6.5 shows the total volume and volume per ha by Forest Class respectively. The Coniferous Forest has greater volume per ha (308.54 m^3 ha^1) compared to the Broadleaved Forest (273.27 m^3 ha^{-1}) which is evident from the volume per ha estimate by different Forest Types.

Table 6.4 Total volume by Forest Class

Forest Class	Volume (m^3)	MoE (%)	Lower Limit	Upper limit
Broadleaved Forest	497,257,910.57	5.23	471,267,144.43	523,248,676.71
Coniferous Forest	264,388,045.88	8.33	242,374,403.97	286,401,687.78

Table 6.5 Volume per ha by Forest Class

Forest Class	Volume (m^3 ha^{-1})	MoE (%)	Lower Limit	Upper limit
Broadleaved Forest	273.27	4.49	261.01	285.53
Coniferous Forest	308.54	7.37	285.81	331.27

The volume per ha by Forest Type varies and ranges from 101.04 m^3 ha^{-1} to 442.7 m^3 ha^{-1} for Juniper Rhododendron Forest and Hemlock Forest respectively (Table 6.6). In general, all Coniferous Forest except Juniper Rhododendron Forest has an average volume per ha greater than the overall volume per ha of the Forest. Among the Broadleaved Forest, only Cool Broadleaved Forest has volume per ha greater than the National average (283.65 m^3 ha^{-1}).

Table 6.6 Volume per ha by Forest Type

Forest Type	Volume (m^3 ha^{-1})	MoE (%)	Lower Limit	Upper Limit
Subtropical Forest	160.90	8.48	147.26	174.54
Chir Pine Forest	116.93	22.78	90.30	143.56
Warm Broadleaved Forest	228.03	7.03	212.00	244.07
Evergreen Oak Forests	341.01	30.02	238.64	443.39
Cool Broadleaved Forest	379.15	5.83	357.05	401.25
Blue Pine Forest	209.17	21.25	164.72	253.63
Spruce Forest	384.84	22.98	296.41	473.26
Hemlock Forest	442.70	17.95	363.24	522.16
Fir Forest	398.82	7.85	367.51	430.13
Juniper Rhododendron Forest	101.04	37.08	63.58	138.50

Further, the total growing stock is mostly contributed by a few Forest Types as shown in Figure 6.2. The three Forest types of Cool Broadleaved Forest, Fir Forest and Warm Broadleaved Forest constitute more than three fourth of the total growing stock. The total growing stock is smallest in Juniper Rhododendron Forest with 7.04 million m^3 of standing volume while the greatest total growing stock is estimated for Cool Broadleaved Forest (285.94 million m^3).

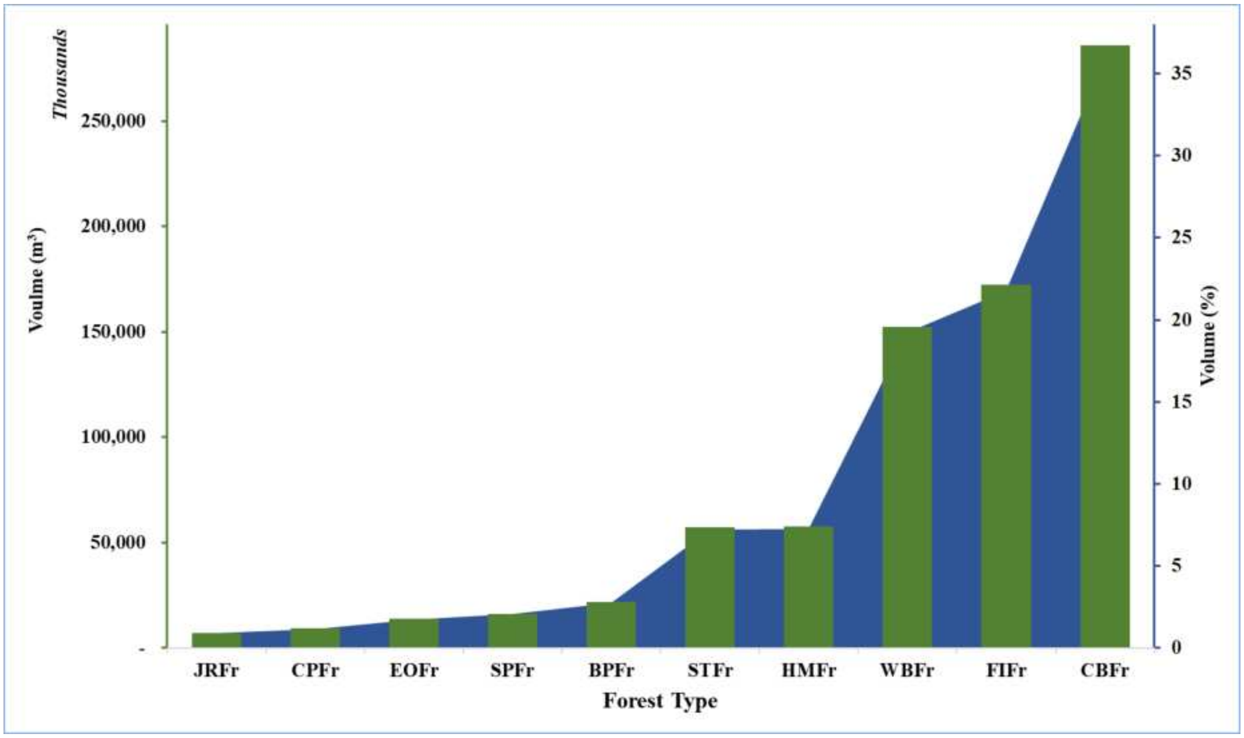


Figure 6.2 Proportion of growing stock by Forest Type

6.2.4 Volume by Elevation

Table 6.7 shows the volume per hectare by elevation range while Figure 6.3 shows the total volume in forest by Elevation. Volume per ha increases with increasing elevation and peaks in the elevation ranges of 2000-3000 *m.a.s.l* and then declines. The greatest volume per ha of 372.46 m^3 ha^{-1} is estimated at the elevation class of 2000-3000 *m.a.s.l*, which is more than five times the volume for the smallest estimate observed in elevation higher than 4000 *m.a.s.l*. The elevation class of 3000-4000 *m.a.s.l* recorded an estimate of 360.40 m^3 ha^{-1}, wherein the elevation 2000-4000 m.a.s.l together constitute about 62 % of total growing stock.

Table 6.7 Volume per ha by Elevation

Elevation (*m.a.s.l*)	Volume (m^3 ha^{-1})	MoE (%)	Lower Limit	Upper Limit
<1000	153.64	8.79	140.13	167.15
1000-2000	213.13	6.58	199.10	227.15
2000-3000	372.46	5.65	351.40	393.52
3000-4000	360.40	7.24	334.30	386.50
>=4000	70.27	55.77	31.08	109.46

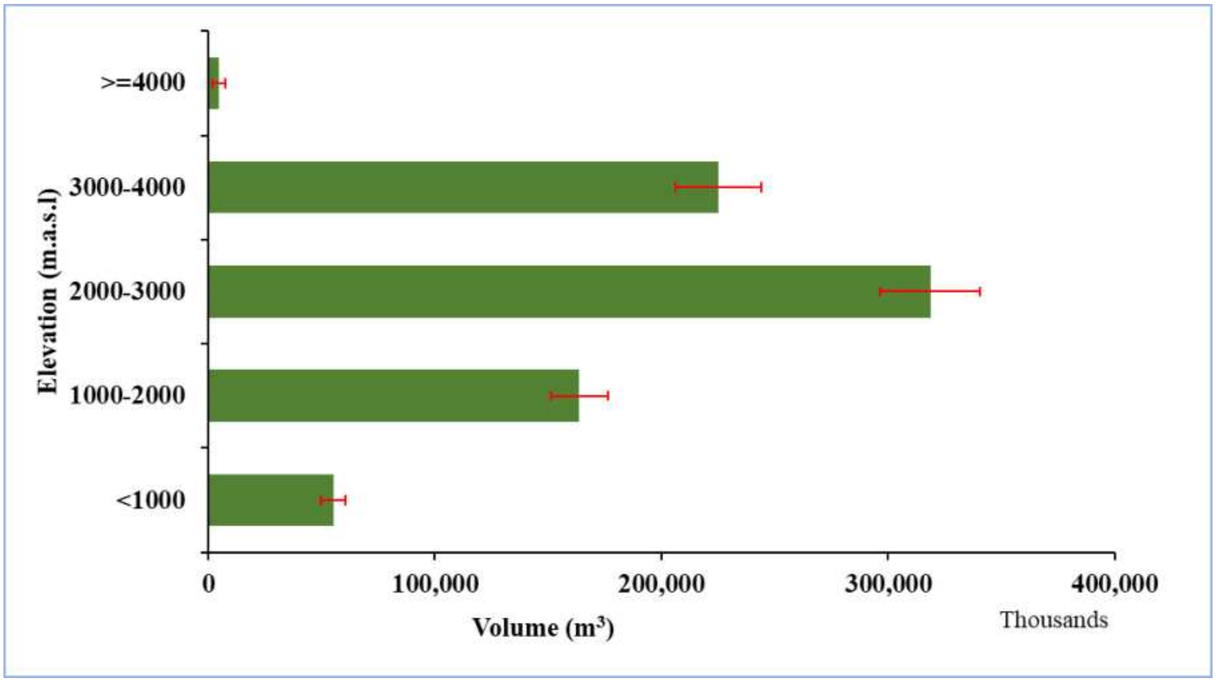


Figure 6.3 Total volume by Elevation

6.2.5 Volume by DBH Class

Table 6.8 shows Volume per ha by DBH class and Figure 4.8 shows the proportion to total volume by DBH class. The lowest Volume per ha is found at 10-20 DBH class (15.49 m^3 ha^{-1}), increasing gradually with increasing DBH Class and reaches a maximum at the 40-50 DBH class (30.24 m^3 ha^{-1}). The Volume then starts to decline gradually beyond DBH class 50-60. The volume per ha is maximum in DBH Class >= 100 cm.

Table 6.8 Volume per ha by DBH Class

DBH Class (cm)	Volume (m^3 ha^{-1})	MoE (%)	Lower Limit	Upper Limit
10-20	15.49	4.02	14.87	16.11
20-30	22.95	3.99	22.03	23.86
30-40	28.46	3.92	27.35	29.58
40-50	30.24	4.63	28.84	31.64
50-60	29.95	5.63	28.27	31.64
60-70	29.56	6.64	27.60	31.52
70-80	26.32	7.65	24.31	28.34
80-90	25.00	8.73	22.81	27.18
90-100	19.24	10.56	17.21	21.27
>=100	56.43	10.79	50.34	62.52

In general, different DBH class contribute from 5% to about 10 % to the total growing stock. Trees in the lowest DBH class 10-20 cm contribute the least to the total growing stock with 41.47 million

m^3 (5.4%) standing volume and DBH class 40-50 cm contribute the most with 80.94 million m^3 (10.67%).

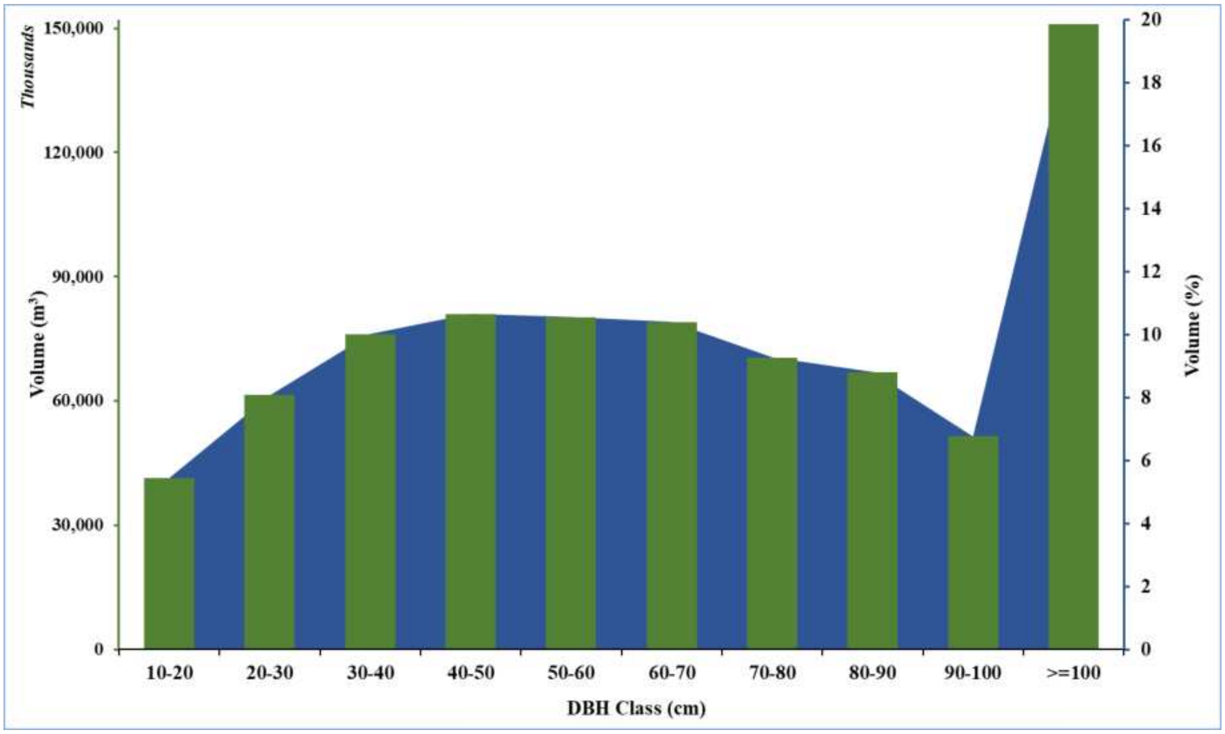


Figure 6.4 Total Volume by DBH Class

6.2.6 Volume by Height Class

Table 6.9 shows tree volume per ha by different Height Class. The volume per ha is greatest in the Height Class 20-25 m and smallest in the Height Class less than 5 m. The volume per ha increases with Height Class and declines sharply after peaking at Height Class 20-25 cm. Figure 6.5 shows the total volume by Height Class.

Table 6.9 Volume per ha by Height Class

Height Class (m)	Volume (m^3 ha^{-1})	MoE (%)	Lower Limit	Upper Limit
<5	0.62	13.62	0.53	0.70
5-10	13.91	5.17	13.19	14.63
10-15	39.21	4.60	37.40	41.01
15-20	55.70	4.85	53.00	58.40
20-25	63.67	6.32	59.64	67.69
25-30	50.74	8.25	46.55	54.92
30-35	29.82	11.84	26.29	33.35
35-40	16.08	16.70	13.40	18.77
>= 40	13.92	27.43	10.10	17.74

As illustrated by Figure 6.5, different contribution of the Height Class to the total volume increases linearly and decreased linearly after peaking. Three Height Classes of 15-20 m, 20-25 m and 25 - 30 m constitute about 60 % of the total growing stock in the Forest and trees with Height Class less than 5 m contribute only about 1.6 million m^3 of volume to growing stock which is less than 1% of the total growing stock.

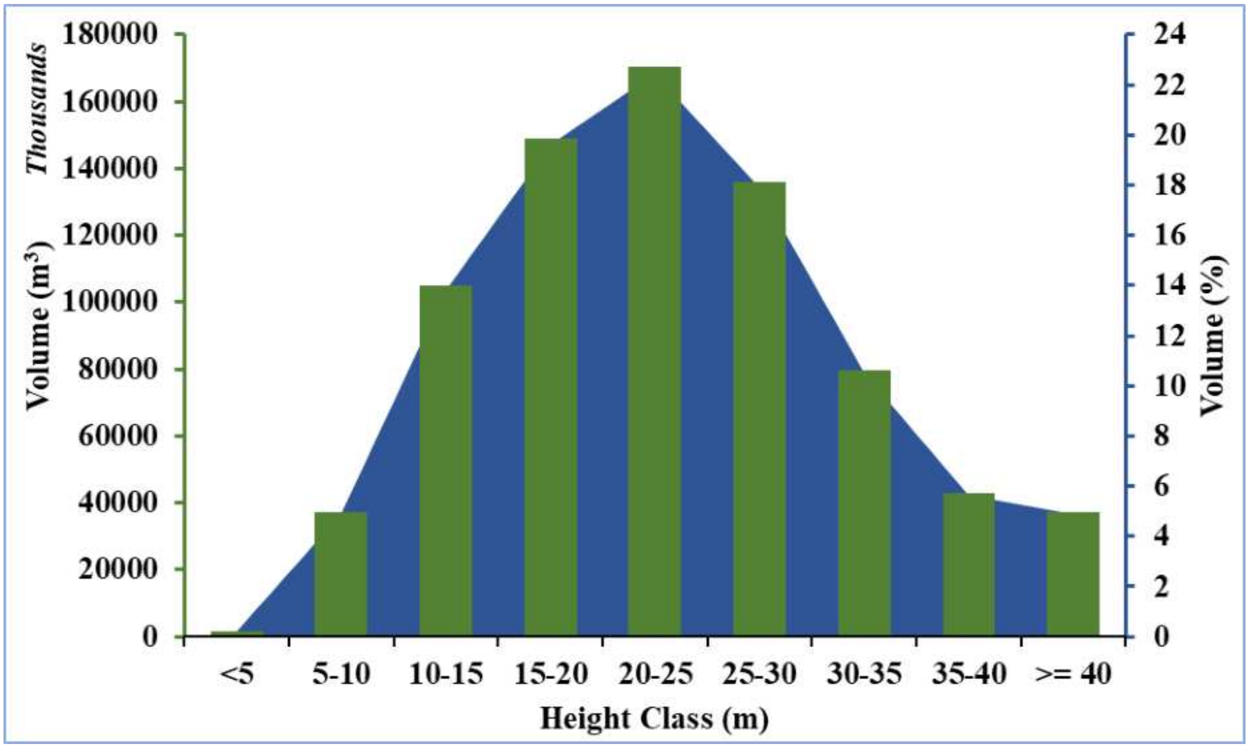


Figure 6.5 Total volume by height class

6.2.7 Volume by Species

Table 6.10 shows the estimate of total volume by species. Fir (*Abies densa)* has the greatest total volume with 126.36 million m^3 standing volume closely followed by Oak (*Quercus spp.*) with a total volume of 115.63 million m^3. These two species constitute more than 30% of the total forest growing stock.

Table 6.10 Total volume by Species

Species	Volume (m^3)	MoE (%)	Lower Limit	Upper Limit
Abies densa	126,358,311.96	14.96	107,455,655.14	145,260,968.78
Acer spp.	27,464,581.43	13.92	23,641,933.97	31,287,228.90
Ailanthus integrifolia	825,582.17	74.8	208,027.82	1,443,136.53
Alnus spp.	9,072,012.93	26.44	6,673,651.90	11,470,373.97
Aphanamixis polystachya	1,219,685.70	53.68	564,918.05	1,874,453.35
Beilschmiedia spp.	7,248,139.84	25.64	5,389,610.90	9,106,668.79

Betula spp.	15,842,099.95	17.91	13,005,471.57	18,678,728.33
Bombax ceiba	1,081,486.78	82.15	193,027.84	1,969,945.71
Castanopsis spp.	33,726,771.33	16.84	28,048,493.37	39,405,049.30
Cupressus spp.	3,240,278.10	171.37	-2,312,633.59	8,793,189.79
Duabanga grandiflora	3,365,339.96	48.22	1,742,637.67	4,988,042.25
Engelhardtia spicata	7,350,016.74	25.8	5,453,541.30	9,246,492.18
Exbucklandia populnea	4,406,075.13	60.86	1,724,581.28	7,087,568.97
Juglans regia	1,067,811.20	53.85	492,831.68	1,642,790.73
Juniperus spp.	10,767,849.63	35.56	6,938,270.61	14,597,428.65
Larix griffithii	893,093.00	67.14	293,481.65	1,492,704.36
Magnolia spp.	7,212,624.72	27.42	5,235,073.93	9,190,175.52
Persea spp.	35,224,349.29	15.52	29,758,732.67	40,689,965.90
Phoebe goalparensis	904,835.58	76.44	213,146.93	1,596,524.24
Picea spinulosa	14,418,763.64	37.14	9,063,883.80	19,773,643.48
Pinus roxburghii	9,483,631.87	32.83	6,370,168.18	12,597,095.56
Pinus wallichiana	23,770,425.67	27.41	17,254,968.49	30,285,882.85
Quercus spp.	115,631,771.24	12.01	101,741,866.23	129,521,676.25
Rhododendron spp.	26,758,432.13	12.4	23,440,199.48	30,076,664.78
Schima wallichii	9,481,713.49	23.68	7,236,188.77	11,727,238.22
Sterculia villosa	1,218,244.91	50.2	606,650.23	1,829,839.60
Symplocos spp.	7,884,698.48	18.22	6,447,857.92	9,321,539.04
Taxus baccata	1,773,993.94	40.01	1,064,186.49	2,483,801.38
Terminalia myriocarpa	2,294,550.43	69.14	708,182.56	3,880,918.29
Tetrameles nudiflora	2,315,910.15	57.89	975,115.43	3,656,704.87
Tsuga dumosa	36,612,290.05	24.65	27,586,834.99	45,637,745.11
Others	210,173,551.96	6.59	196,332,205.84	224,014,898.08

6.3 Discussion

The total growing stock of Forests and Non-Forests is 759 ±33 million m^3 and 14 ±5 million m^3 respectively. The growing stock of our forest (283.65 m^3 ha^{-1}) is about 100 % greater than the global average of 137 m^3 ha^{-1} (FAO, 2020) and very high compared to the growing stock in neighboring Indian State of Assam (41.99 m^3 ha^{-1}), Arunachal Pradesh (81.2 m^3 ha^{-1}), West Bengal (51.51 m^3 ha^{-1}) and Sikkim (58.06 m^3 ha^{-1}) (FSI, 2021). However, there is a decrease in the growing stock in both Forest and Non-Forest compared to the growing stock of 1st NFI (FRMD, 2016b). The decline in the total growing stock is the result of marginal decrease in Forest area from 2.73 million ha to 2.67 million ha as well as a decrease in growing stock density in Forest and Non-Forests. The growing stock per unit area is estimated to be 283.65 ±10.96 m^3 ha^{-1} which is about 18% decrease from 346 m^3 ha^{-1}.

The decrease in growing stock from 2016 to 2021 may also be attributed to the removal of bigger trees and low rate of replacement by younger trees and saplings due to the prolonged period required for the tree to mature (Roux et al., 2014). This is evident from the decrease in volume per ha of larger DBH class while the volume per ha of smaller trees has increased. For instance, the volume per ha for DBH class greater than 100 cm had decreased from 83 m^3 ha^{-1} in 2016 (FRMD, 2016) to 56.65 m^3 ha^{-1} in 2022. Records maintained by Department of Forests and Park Services shows that about 71,241.95 ha of SRF land were allotted on lease, land substitute, transmission lines and other development activities between 2016 to 2022 and 1.5 million m^3 of timber was allotted directly by the Department during the same period.

In addition, contrary to the greater volume per ha in Coniferous Forest in comparison to the Broadleaved Forest, the Broadleaved Forest accounts for more than two third of the total growing stock (Figure 6.6). Broadleaved Forest also recorded the greatest numbers of trees but poor regeneration. Therefore, sustainable management of the Broadleaved Forest in the country needs serious consideration.

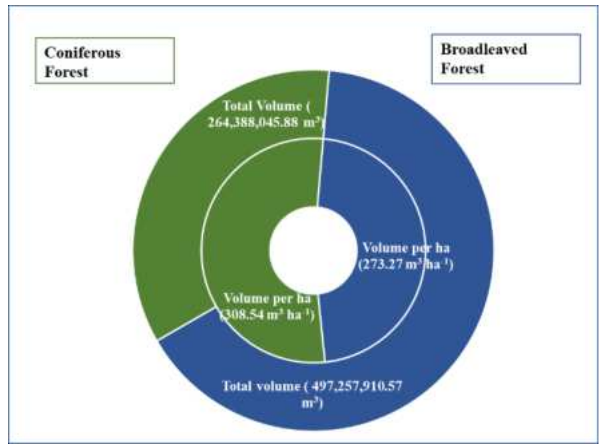


Figure 6.6 Comparison of growing stock in Broadleaved and Coniferous Forest

Further, the growing stock density of all Broadleaved Forest (except cool broadleaved forest) saw increase in volume per ha while all Conifer Forests has substantially decreased in volume per ha. This was a strong indication of Forest degradation in Coniferous Forest and warrant detail investigation for restocking and promoting the growth of the Coniferous Forests.

BASAL AREA INCREMENT

7 BASAL AREA INCREMENT

7.1 Introduction

Forest growth and increment plays important role in sustainable forest management and the determination of a sustainable level of forest (Tomter et al., 2016) . The forest growth and increment, particularly basal area increment and volume increment can be estimated using different methods such as repeated measurement of the permanent sample plots, increment coring, and using growth models and yield tables (Chen et al., 2018; Tenzin & Hasenauer, 2016; Tomppo, 2006; Tomter et al., 2016). Basal area increment is estimated through the tree ring analysis method, one of the widely used and best alternatives to whole stem analysis (Metsaranta & Bhatti, 2016) and provide a reliable estimate with no significant difference from other methods (O'Flanagan, 1961).

Tree cores were collected from QAQC plots as per the modalities defined in the NFI Manual and prescribed in the *Code* (DoFPS, 2021b). Over 4000 tree rings of different tree and diameter class were collected using the *Haglof* increment borer and transferred to the tree ring laboratory, UWIFoRT for measurement of the width of the tree ring. Accordingly, the radial increment for that particular tree for a 5-year growth period is recorded. The radial increment is multiplied by two to obtain the diameter increment (Young & Giese, 2003) for the 5-year growth period. These diameter increment data are used to reconstruct the DBH at the beginning of the growth period, which is five years prior to the current DBH measurement. The periodic annual basal area increment (BAI) for 5 years is estimated using the equation (7.1) (Assmann, 1970; Tenzin & Hasenauer, 2016) . The BAI per unit area is obtained by dividing the mean annual basal area increment by plot area.

$$BAI_i = \frac{\frac{\pi}{4}\left(2\ x\ d_1 + I_d + I_d^2\right)}{5} \qquad (7.1)$$

Where,

BAI_i, is the 5- year periodic annual basal area increment, m^2 /year;

d_1, is the dbh at the beginning of the growth period, m; and

I_d, is the 5- year diameter increment at bh, m.

7.2 Basal Area Increment

Basal area increment (BAI) refers to the increase in the basal area over a defined period of time. It provides information about the growth and productivity of the individual trees as well as the entire stand. The basal increments are estimated as described above and reported at various reporting units.

7.2.1 Basal Area Increment by Land Class

The periodic annual BAI varies significantly between trees in Forest and Non-Forests (Table 7.1). This indicates that the trees are growing faster in the Forest than the tree in the Non-Forest. The BAI has decreased marginally since the last BAI reported in 2018 from the forest inventory data of 2012 to 2015. The total annual BAI in last five years in forest is 1.22 million m^2 for the entire Forest (Table 7.2).

Table 7.1: Basal area increment in Forest and Non-Forest

Land Type	BAI (m^2 ha^{-1} yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Forest	0.46	9.98	0.41	0.50
Non-Forest	0.16	72.27	0.04	0.28

Table 7.2 Total basal area increment in Forest and Non-Forest

Land Type	BAI (m^2 yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Forest	1,220,242.60	10.15	1,096,377.28	1,344,107.92
Non-Forest	186,552.60	72.30	51,681.21	321,424.00

7.2.2 Basal Area Increment by Dzongkhag

The periodic annual BAI in the Dzongkhags varies greatly from 0.18 m^2 ha^{-1} yr^{-1} in Lhuentse Dzongkhag to 1.03 m^2 ha^{-1} yr^{-1} in Pemagatshel Dzongkhag. The BAI in most of the Dzongkhags are below the national average of 0.46 m^2 ha^{-1} yr^{-1}. Table 7.3 and Figure 7.1 shows the annual BAI per hectare and total basal increment per year respectively by Dzongkhag.

Table 7.3: Basal area increment by Dzongkhags

Dzongkhag	BAI (m^2 ha-^{1} yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Bumthang	0.40	37.47	0.25	0.55
Chhukha	0.40	44.89	0.22	0.58
Dagana	0.52	19.96	0.42	0.63
Gasa	0.20	31.08	0.14	0.26
Haa	0.31	35.09	0.20	0.42
Lhuentse	0.18	68.28	0.06	0.31
Mongar	0.41	56.43	0.18	0.64
Paro	0.59	48.43	0.30	0.88
Pemagatshel	1.03	72.14	0.29	1.77
Punakha	0.57	28.70	0.41	0.74
Samdrup Jongkhar	0.44	25.23	0.33	0.56
Samtse	0.33	28.10	0.23	0.42
Sarpang	0.43	25.34	0.32	0.54
Thimphu	0.49	28.06	0.35	0.62
Trashigang	0.50	25.87	0.37	0.63

Trashi Yangtse	0.43	41.24	0.25	0.60
Trongsa	0.29	36.00	0.19	0.39
Tsirang	0.61	27.38	0.44	0.78
Wangdue Phodrang	0.34	22.69	0.26	0.41
Zhemgang	0.75	37.39	0.47	1.03

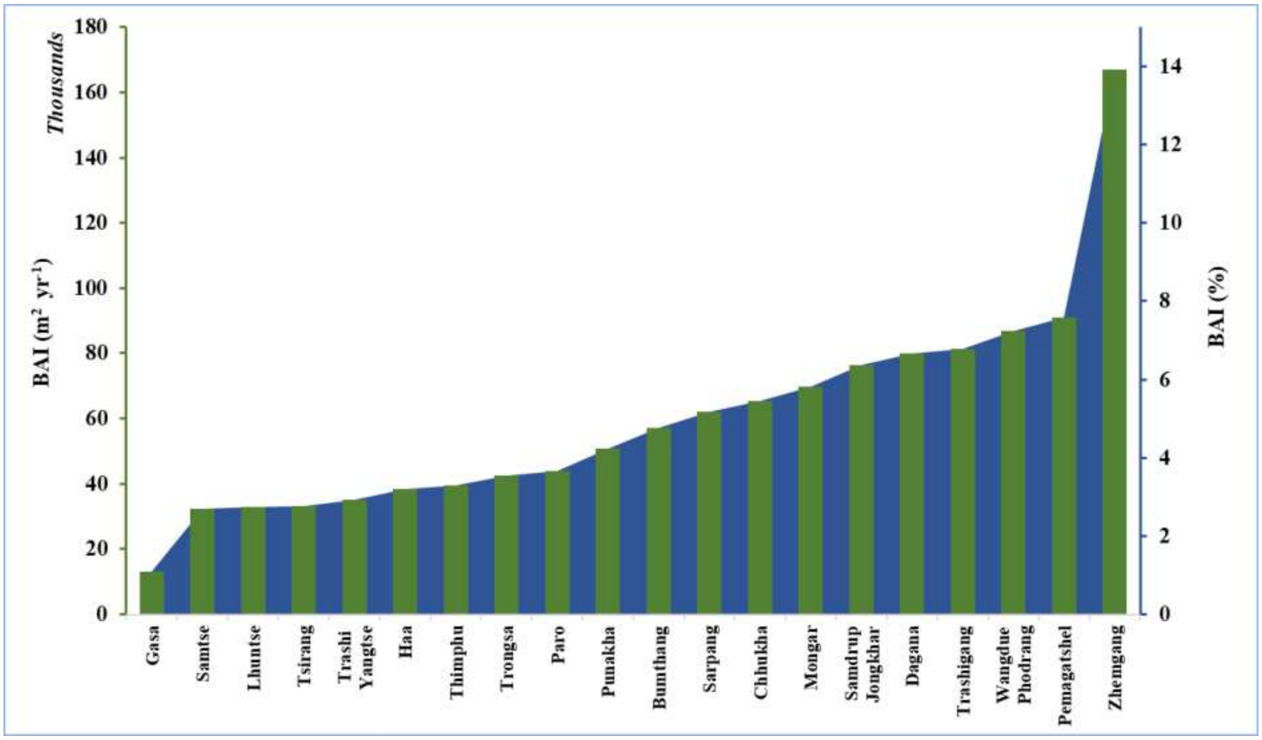


Figure 7.1 Total basal area increments by Dzongkhag

7.2.3 Basal Area Increment by Forest Type

Table 7.4 and Table 7.5 shows the BAI per ha and total BAI by Forest Class respectively. Broadleaved Forest has greater BAI per ha (0.48 $m^2 ha^{-1} yr^{-1}$) compared to Coniferous Forest (0.40 $m^2 ha^{-1} yr^{-1}$). The total BAI in Broadleaved and Coniferous Forest is 0.875 million $m^2 yr^{-1}$ and 0.340 $m^2 yr^{-1}$ respectively.

Table 7.4 Basal area increment per ha by Forest Class

Forest Class	BAI ($m^2 ha^{-1} yr^{-1}$)	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	0.48	11.68	0.42	0.54
Coniferous Forest	0.40	18.86	0.32	0.47

Table 7.5 Total basal area increment by Forest Class

Forest Class	BAI ($m^2 yr^{-1}$)	MoE (%)	Lower Limit	Upper Limit
Broadleaved Forest	874,643.58	4.35	836636.39	912650.76
Coniferous Forest	339,837.25	5.82	320044.34	359630.16

Table 7.6 and Figure 7.2 shows the BAI per ha and total BAI by Forest Types. The periodic annual BAI in Forest Type ranges from 0.14 m^2 ha^{-1} yr^1 to 0.68 m^2 ha^{-1} yr^{-1}. BAI in Subtropical Forest, Warm Broadleaved Forest, Blue Pine Forest and Spruce Forest are greater than the national average while other forest types have smaller BAI than the national average. The greatest BAI was recorded in Blue Pine Forest at 0.68 m^2 ha^{-1} yr^{-1} while the Juniper Rhododendron Forest has the smallest BAI of 0.14 m^2 ha^{-1} yr^1.

Table 7.6 Basal area increment per ha by Forest Type

Forest Type	BAI (m^2 ha^{-1} yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Subtropical Forest	0.54	27.39	0.39	0.69
Chir Pine Forest	0.28	54.87	0.13	0.43
Warm Broadleaved Forest	0.53	19.18	0.43	0.64
Evergreen Oak Forests	0.20	79.35	0.04	0.35
Cool Broadleaved Forest	0.40	12.91	0.35	0.45
Blue Pine Forest	0.68	41.85	0.40	0.97
Spruce Forest	0.55	73.07	0.15	0.96
Hemlock Forest	0.43	41.01	0.25	0.60
Fir Forest	0.40	24.20	0.31	0.50
Juniper Rhododendron Forest	0.14	59.63	0.06	0.23

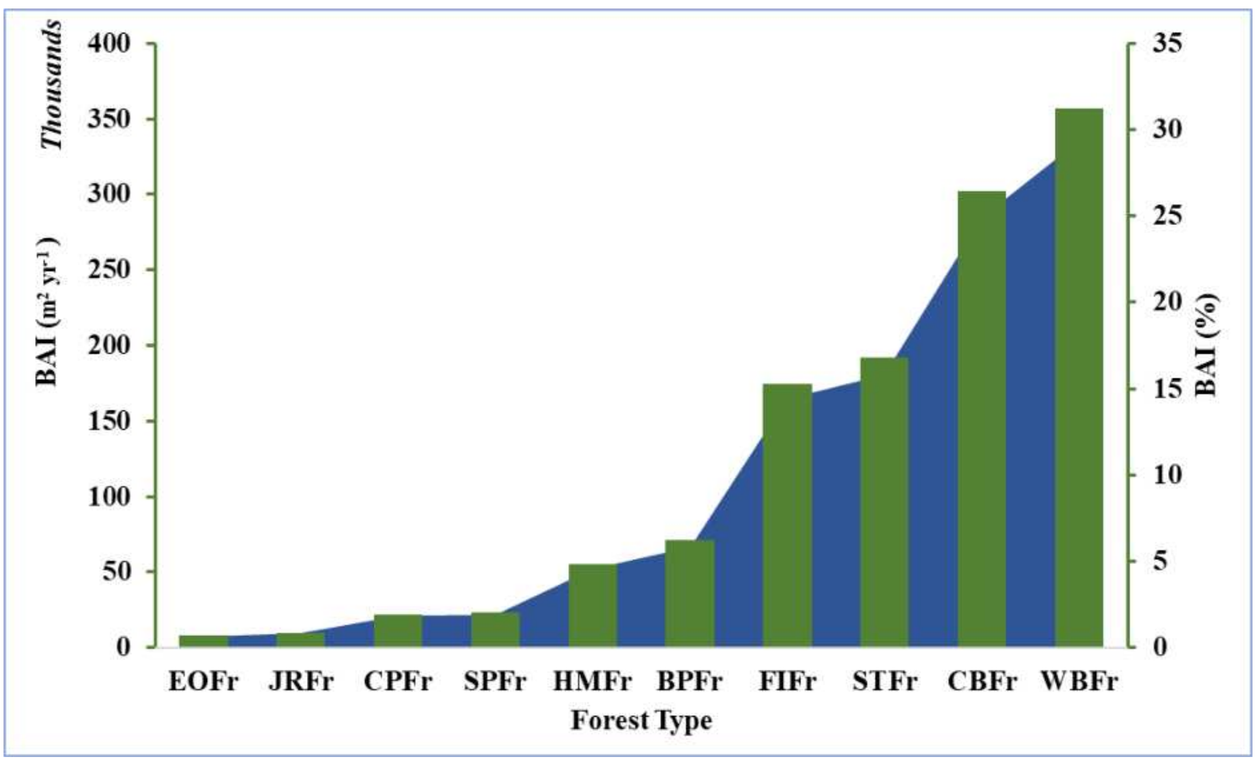


Figure 7.2 Total basal area increment by forest type

7.2.4 Basal Area Increment by Elevation

Table 7.6 and Figure 7.3 shows the periodic annual BAI per ha and total BAI in the Forest by elevation. BAI ranges from 0.09 $m^2 ha^{-1} yr^{-1}$ to 0.53 $m^2 ha^{-1} yr^{-1}$ and shows an inverse relationship, where the BAI is greatest in lower elevation and smallest in higher elevation range. The BAI by elevation range show a similar trend to the increment discussed in the 1st NFI (FRMD, 2018b).

Table 7.7 Basal area increment per ha by elevation

Elevation	BAI ($m^2 ha^{-1}yr^{-1}$)	MoE(%)	Lower Limit	Upper Limit
<1000	0.53	28.24	0.38	0.68
1000-2000	0.52	19.16	0.42	0.63
2000-3000	0.45	14.10	0.38	0.51
3000-4000	0.39	17.88	0.32	0.46
>=4000	0.09	58.46	0.04	0.14

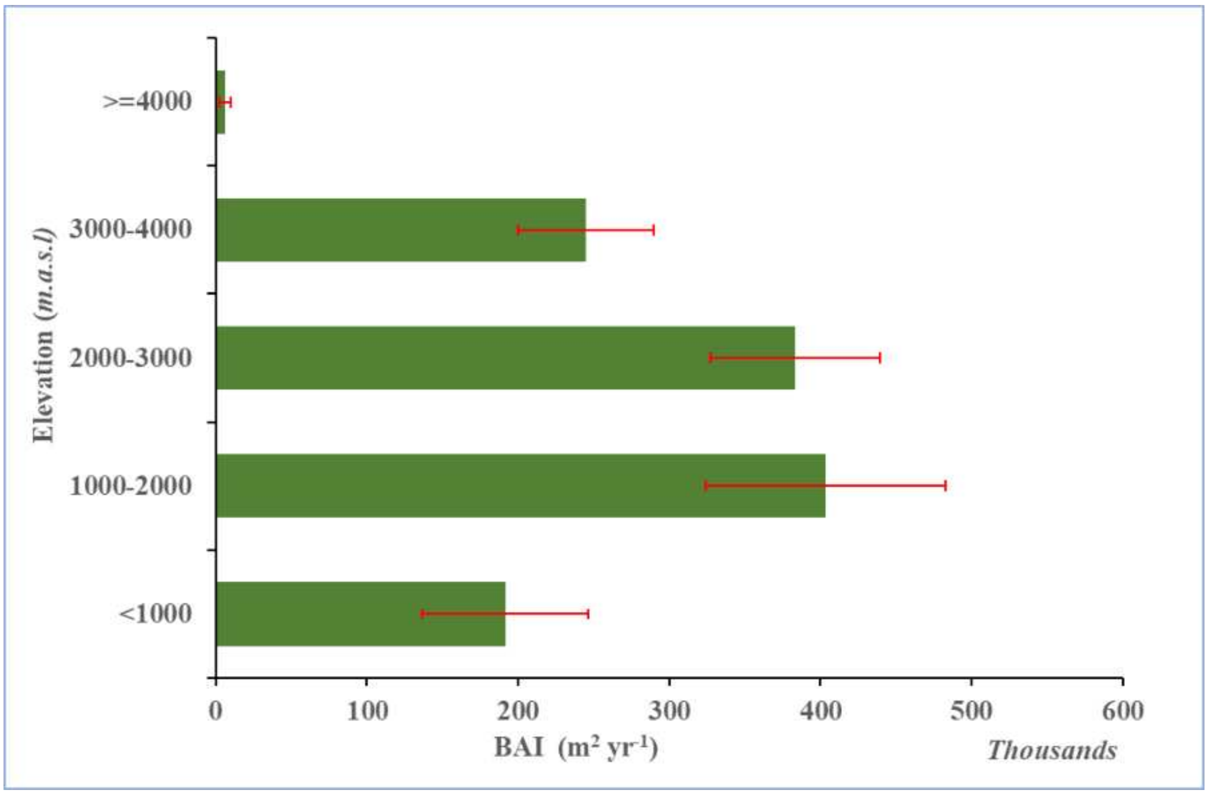


Figure 7.3 Total basal area increment by Elevation

7.2.5 Basal Area Increment by Species

Table 7.8 and Table 7.9 shows periodic annual BAI per ha and total BAI by species. The BAI varies significantly among different tree species. The greatest periodic BAI is recorded in *Quercus* spp. (0.007 $m^2 ha^{-1}yr^{-1}$) followed by *Abies densa* (0.006 $m^2 ha^{-1}yr^{-1}$) and *Rhododendron* spp. (0.006 $m^2 ha^{-1}yr^{-1}$). The total BAI is greatest for *Quercus* spp. (19,038 $m^2 ha^{-1} yr^{-1}$) and smallest for *Duabanga grandiflora* (59 $m^2 yr^{-1}$).

Table 7.8 Basal area increment per ha by Species

Species	BAI (m^2 ha^{-1} yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Abies densa	0.00582	36.837	0.00368	0.00797
Acer spp.	0.00309	35.574	0.00199	0.00419
Ailanthus integrifolia	0.00013	122.772	(0.00003)	0.00029
Alnus spp.	0.00163	70.394	0.00048	0.00278
Aphanamixis polystachya	0.00013	150.024	(0.00007)	0.00034
Beilschmiedia spp.	0.00132	48.783	0.00067	0.00196
Betula spp.	0.00176	64.610	0.00062	0.00290
Castanopsis spp.	0.00463	62.263	0.00175	0.00752
Cupressus spp.	0.00015	200.000	(0.00015)	0.00045
Duabanga grandiflora	0.00002	200.000	(0.00002)	0.00007
Engelhardtia spicata	0.00198	68.814	0.00062	0.00335
Exbucklandia populnea	0.00051	81.417	0.00009	0.00092
Juglans regia	0.00021	181.026	(0.00017)	0.00058
Juniperus spp.	0.00173	59.586	0.00070	0.00276
Larix griffithii	0.00007	188.725	(0.00006)	0.00020
Magnolia spp.	0.00045	83.654	0.00007	0.00082
Persea spp.	0.00284	30.035	0.00199	0.00369
Phoebe goalparensis	0.00010	143.398	(0.00005)	0.00025
Picea spinulosa	0.00153	70.411	0.00045	0.00261
Pinus roxburghii	0.00066	82.642	0.00011	0.00120
Pinus wallichiana	0.00433	70.957	0.00126	0.00741
Quercus spp.	0.00711	44.705	0.00393	0.01029
Rhododendron spp.	0.00580	29.523	0.00408	0.00751
Schima wallichii	0.00185	44.336	0.00103	0.00266
Sterculia villosa	0.00008	200.000	(0.00008)	0.00025
Symplocos spp.	0.00202	38.618	0.00124	0.00279
Taxus baccata	0.00014	114.401	(0.00002)	0.00030
Terminalia myriocarpa	0.00011	200.000	(0.00011)	0.00033
Tetrameles nudiflora	0.00050	200.000	(0.00050)	0.00150
Tsuga dumosa	0.00214	66.474	0.00072	0.00356
Others	0.03877	13.650	0.03348	0.04406

Table 7.9 Total basal area increment by species

Species	BAI (m^2 yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Abies densa	15,588.09	36.88	9,838.53	21,337.65
Acer spp.	8,273.55	35.62	5,326.27	11,220.84
Ailanthus integrifolia	343.78	122.79	(78.33)	765.89

Alnus spp.	4,372.90	70.42	1,293.54	7,452.27
Aphanamixis polystachya	360.43	150.04	(180.34)	901.20
Beilschmiedia spp.	3,527.17	48.82	1,805.27	5,249.07
Betula spp.	4,710.49	64.64	1,665.78	7,755.20
Castanopsis spp.	12,398.60	62.29	4,675.40	20,121.80
Cupressus spp.	397.04	200.01	(397.08)	1,191.16
Duabanga grandiflora	59.15	200.01	(59.16)	177.46
Engelhardtia spicata	5,304.03	68.84	1,652.77	8,955.29
Exbucklandia populnea	1,355.20	81.44	251.55	2,458.86
Juglans regia	553.51	181.04	(448.53)	1,555.55
Juniperus spp.	4,625.20	59.62	1,867.86	7,382.54
Larix griffithii	184.23	188.73	(163.48)	531.94
Magnolia spp.	1,195.10	83.67	195.10	2,195.09
Persea spp.	7,601.72	30.09	5,314.11	9,889.32
Phoebe goalparensis	280.21	143.41	(121.64)	682.05
Picea spinulosa	4,092.62	70.44	1,209.97	6,975.28
Pinus roxburghii	1,763.66	82.66	305.77	3,221.55
Pinus wallichiana	11,594.88	70.98	3,364.61	19,825.14
Quercus spp.	19,038.39	44.74	10,519.81	27,556.98
Rhododendron spp.	15,513.42	29.58	10,924.25	20,102.60
Schima wallichii	4,940.96	44.38	2,748.39	7,133.54
Sterculia villosa	226.84	200.01	(226.86)	680.53
Symplocos spp.	5,394.50	38.66	3,308.82	7,480.19
Taxus baccata	371.07	114.42	(53.49)	795.63
Terminalia myriocarpa	292.90	200.01	(292.93)	878.73
Tetrameles nudiflora	1,338.70	200.01	(1,338.81)	4,016.21
Tsuga dumosa	5,728.72	66.50	1,919.10	9,538.33
Others	103,762.04	13.78	89,467.08	118,056.99

7.3 Discussion

Increment is the increase in growth, diameter, volume, height and other parameters over a period of time. Subsequently, periodic annual increment in terms of BAI and volume increment was estimated to provide a better understanding of the increment in Bhutan's Forests. The periodic BAI increment in the Forests is estimated to be 0.46 ±0.05 $m^2\ ha^{-1}\ yr^{-1}$ showing a growth rate of 1.4% annually in terms of basal area in the last five years. In absolute terms, BAI has decreased from 0.48 ±0.05 $m^2\ ha^{-1}\ yr^{-1}$ for the 5-year growth period reported in the 1st NFI (FRMD, 2018b). However, the actual BAI growth rate has increased from 1.2% to 1.4% in the last five-year growth period. BAI in Bhutan's Forest is also smaller than the BAI growth of 2.05% in the Tropical Forest of India (Rai, 2016).

Among the Dzongkhags, the basal area growth is generally greater in Dzongkhag where Broadleaved Forest and Blue Pine Forest are predominant. Pemagatshel and Zhemgang Dzongkhags which has the majority of Broadleaved Forest have greater BAI per ha per year compared to other Dzongkhags. Further, BAI growth is greater in younger trees, which gradually increases, stabilizes and then declines (Coomes & Allen, 2007a). Greater BAI in some Dzongkhags with greater tree density could be explained by the presence of a large number of trees in the smaller diameter class.

The basal area growth is affected by tree specific factors, environmental conditions, disturbance, climate, soil, species mixtures and harvesting (Coomes & Allen, 2007b; FRMD, 2018b; Vospernik, 2021) and growth has a positive correlation with environmental factors (Báez et al., 2015; Chen et al., 2018). Therefore, the variation in the BAI of different forest type and species need further investigation in Bhutan. Lower BAI in higher elevations may be the result of lower temperature and shorter growing seasons and vice versa in lower elevations. In general, inverse relation of BAI with elevation is observed (Coomes & Allen, 2007b)

Understanding the BAI and management of stands with greater growth such as Broadleaved Forest and Blue Pine Forest is critical and may lead to enhanced timber timber production, which shall benefit the current and future demand for conifer timber in Bhutan.

REGENERATION

8 REGENERATION

8.1 Introduction

Regeneration is defined in many ways; the most common being the process of regenerating or the renewal of forest stands. It is also used to refer to the new growth that is regenerating. For the purpose of NFI, all tree species with DBH less than 5 cm and located within the 3.57 m subplot of the "L" plot were enumerated and recorded as regeneration. Regeneration was further classified as recruits, un-established and established. Tree species having DBH less than 5 cm and of height more than 2 m were classified as established regeneration while those with height less than 2 m were classified as un-established regeneration. All current year seedlings with 2-4 leaves were classified as recruits (DoFPS, 2021b). The plot design for the collection of regeneration data is described in section 2.1.1 Sampling Design of Chapter 2 METHODOLOGY.

In each plot, the regeneration of different tree species in the plot is recorded and summed up by the type of regeneration. This is then extrapolated to the per ha level using equation (8.1).

$$R_d = \left(\frac{R_n}{R_a}\right)$$

(8.1)

Where,

R_d is regeneration density in the CP;
R_n is the number of regenerations; and
R_a is the regeneration plot area.

The regeneration plot area, Ra is estimated using equation (8.2)

$$R_a = \pi * (\frac{P_d}{2})^2$$

(8.2)

R_a is the regeneration plot area in ha; and
P_d is the diameter of the regeneration plot in meter.

Regeneration density is then estimated at per ha level for each plot/CP, and total estimates are obtained by multiplying the per ha estimates with the total area of the study or the total forests. The same is applied for all three types of regeneration reported for the NFI.

8.2 Regeneration by Different Categories

Regeneration by Land AreaTable 8.1 shows the total regeneration by different regeneration types in Forest and Non-Forest. Forest has a greater number of recruits (2,134 million). However, the number of unestablished regenerations is greater than established regeneration in both Forest and Non-Forest.

Table 8.1 Total regeneration by Forest and Non-Forest

Regeneration type	Number	MoE (%)	Lower Limit	Upper Limit
Forest				
Recruits	2,134,601,964	25	1,602,060,447	2,667,143,481
Unestablished Regeneration	1,730,862,382	11	1,548,008,446	1,913,716,318
Established Regeneration	1,434,900,739	10	1,290,542,786	1,579,258,692
Non-Forest				
Recruits	244,373,422	50	123,251,095	365,495,750
Unestablished Regeneration	422,954,000	102	(9,665,109)	855,573,110
Established Regeneration	340,712,945	59	138,346,173	543,079,716

The regeneration density differs greatly between Forest and Non-Forest. Forest has recorded 798, 647 and 536 No. ha^{-1} of recruits, unestablished and established regeneration respectively while Non-Forest recorded 210, 364 and 293 No. ha^{-1} of recruits, unestablished and established regeneration respectively (Table 8.2).

Table 8.2 Regeneration per ha by Forest and Non-Forest

Regeneration type	Number ha^{-1}	MoE (%)	Lower Limit	Upper Limit
Forest				
Recruits	798	24.88	599	996
Unestablished Regeneration	647	10.40	579	714
Established Regeneration	536	9.89	483	589
Non-Forest				
Recruits	210	49.53	106	314
Unestablished Regeneration	364	102.27	(8)	736
Established Regeneration	293	59.37	119	467

8.3 Regeneration by Dzongkhag

The total count of recruits, unestablished and established regeneration in different Dzongkhag is shown in Table 8.3. Bumthang has the greatest number of recruits (4,148 No. ha^{-1}). Thimphu has the second greatest with 1,975 recruit ha^{-1} while Punakha (83 No. ha^{-1}) and Chhukha (117 No. ha^{-1}) has the least number of recruits. Dagana has recorded 537 No. ha^{-1} of recruits and the greatest number of unestablished regeneration (1167 No. ha^{-1}). Similarly, Zhemgang recorded a recruit density of 578 No. ha^{-1} and the greatest number of established regenerations at 959 No. ha^{-1}. In general, Chukha Dzongkhag has a lower number of recruits (117 No. ha^{-1}); and the smallest number of unestablished and established regeneration of 102 and 100 No. ha^{-1} respectively.

Table 8.3 Regeneration per ha by Dzongkhag

Dzongkhag	Recruits		Unestablished Regeneration		Established Regeneration	
	Number ha^{-1}	MoE (%)	Number ha^{-1}	MoE (%)	Number ha^{-1}	MoE (%)
Bumthang	4,148	65	462	42	187	53
Chhukha	117	85	102	56	100	47
Dagana	537	40	1,167	27	821	32
Gasa	882	95	241	79	558	67
Haa	539	57	718	55	543	53
Lhuentse	253	103	434	70	274	53
Mongar	1,056	150	304	39	271	48
Paro	1,369	56	1,104	70	470	55
Pemagatshel	250	96	714	52	789	49
Punakha	83	98	1,093	56	401	61
Samdrup Jongkhar	504	50	497	23	846	19
Samtse	888	36	784	29	284	35
Sarpang	1,086	69	623	33	778	34
Thimphu	1,975	47	504	69	336	51
Trashigang	295	55	327	36	381	33
Trashi Yangtse	177	90	331	44	549	53
Trongsa	127	96	753	38	461	52
Tsirang	808	46	742	48	463	44
Wangdue Phodrang	567	41	771	33	699	41
Zhemgang	578	41	1,155	30	959	21

Table 8.4 shows the total regeneration in the Dzongkhag. Total regeneration ranges from 7.38 million (Punakha) to 589 million (Bumthang) for recruits, 15.81 million (Gasa) to 258 million (Zhemgang) for unestablished regeneration and 16.27 million (Chhukha) to 213.85 million (Zhemgang) for established regeneration.

Table 8.4 Total Regeneration by Dzongkhag

Dzongkhag	Recruits		Unestablished Regeneration		Established Regeneration	
	Number ha^{-1}	MoE (%)	Number ha^{-1}	MoE (%)	Number ha^{-1}	MoE (%)
Bumthang	589,147,528	65	65,642,043	42	26,501,446	53
Chhukha	19,119,486	85	16,678,701	56	16,271,903	47
Dagana	82,301,487	40	179,015,216	27	125,917,482	32
Gasa	57,773,607	95	15,805,987	79	36,517,280	67

Haa	66,609,688	57	88,649,659	55	67,099,465	53
Lhuentse	45,456,131	103	77,835,840	70	49,192,251	53
Mongar	180,925,450	150	52,091,646	39	46,510,398	48
Paro	102,249,262	56	82,471,120	70	35,078,214	55
Pemagatshel	22,152,996	96	63,349,795	52	69,956,829	49
Punakha	7,384,332	98	96,919,357	56	35,537,098	61
Samdrup Jongkhar	86,770,784	50	85,576,691	23	145,679,390	19
Samtse	88,569,382	36	78,217,116	29	28,372,876	35
Sarpang	157,359,143	69	90,300,525	33	112,780,402	35
Thimphu	161,130,679	47	41,116,104	69	27,410,736	51
Trashigang	48,076,077	55	53,253,501	36	62,129,084	33
Trashi Yangtse	14,492,950	90	27,127,830	44	44,965,307	53
Trongsa	18,587,121	96	110,490,110	38	67,636,469	52
Tsirang	43,941,429	46	40,346,221	48	25,166,455	44
Wangdue Phodrang	146,913,357	41	199,580,409	33	181,100,741	41
Zhemgang	128,995,049	41	257,561,543	30	213,848,935	21

8.3.1 Regeneration by Forest Type

Regeneration density in Broadleaved Forest and Coniferous Forest is shown in Table 8.5. Coniferous Forest has a greater number of recruits (1,640 No. ha^{-1}) than Broadleaved Forest (446 No. ha^{-1}) while the Broadleaved Forest has a greater number of unestablished and established regeneration (Table 8.5).

Table 8.5 Regeneration per ha by Forest Class

Regeneration Type	Broadleaved Forest				Coniferous Forest			
	No. ha^{-1}	MoE (%)	Lower Limit	Upper Limit	No. ha^{-1}	MoE (%)	Lower Limit	Upper Limit
Recruits	446	20	358	534	1,640	39	1,007	2,274
Unestablished Regeneration	699	11	620	777	522	25	394	651
Established Regeneration	598	11	535	661	387	25	291	484

Further, Figure 8.1 shows the total number of regenerations by different types. The total regeneration shows similar trends to the regeneration density.

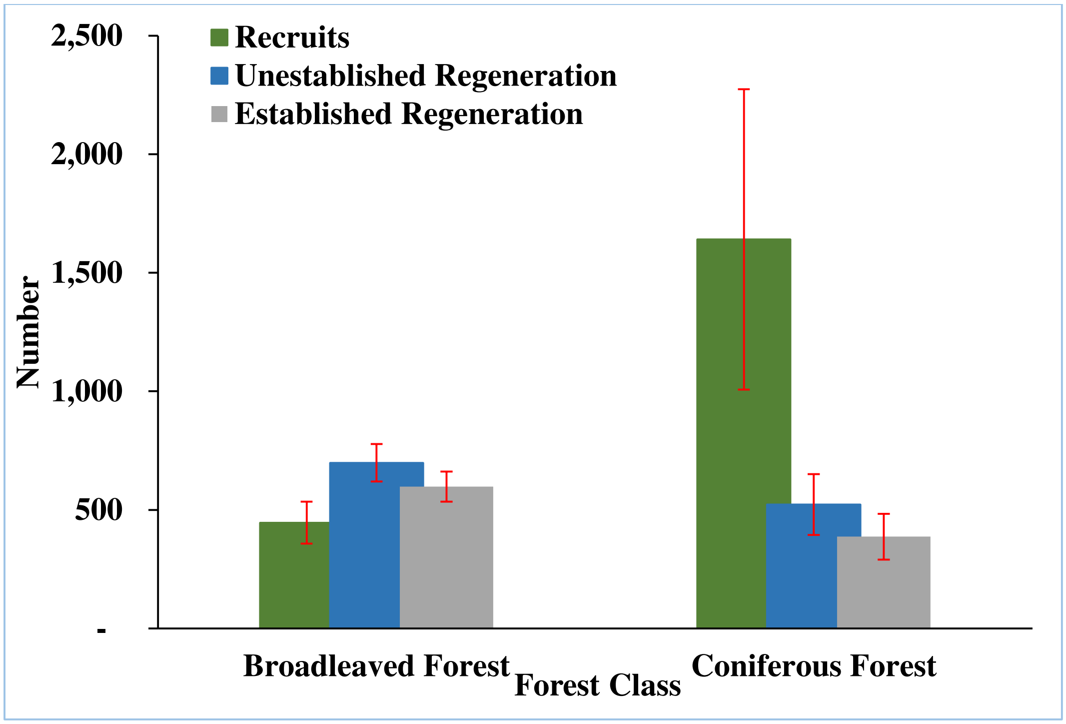


Figure 8.1 Total Regeneration by Forest Class

The regeneration status in different Forest Types is reported in Table 8.6. Blue Pine Forest has the greatest number of recruits (4,477 No. ha^{-1}) indicating the stability and expansion of Blue Pine Stand. Evergreen Oak Forest has the greatest number of unestablished (919 No. ha^{-1}) and established (892 No. ha^{-1}) regeneration. Juniper Rhododendron Forest has the smallest number of recruits (86 No. per ha^{-1}) and unestablished regeneration (227 No. ha^{-1}) while Chir Pine Forest has the smallest number of established regeneration (264 No. ha^{-1}). Chir Pine Forest in general has recorded a smaller regeneration number with 343 No. ha^{-1} of recruits and 264 No. ha^{-1} of unestablished regeneration.

Table 8.6 Regeneration per ha by Forest Type

Forest Type	Recruits		Unestablished Regeneration		Established Regeneration	
	No. ha^{-1}	MoE (%)	No. ha^{-1}	MoE (%)	No. ha^{-1}	MoE (%)
Subtropical Forest	730	43	643	21	805	19
Chir Pine Forest	343	100	264	63	264	59
Warm Broadleaved Forest	393	28	715	20	521	19
Evergreen Oak Forest	740	73	919	70	892	72
Cool Broadleaved Forest	317	28	699	17	539	17

Blue Pine Forest	4,477	75	715	54	447	42
Spruce Forest	1,085	72	701	61	403	97
Hemlock Forest	593	69	598	50	484	96
Fir Forest	1,776	47	561	40	386	38
Juniper Rhododendron Forest	86	94	227	76	341	73

Comparison of the regeneration types in different forest type is shown in Figure 8.2.

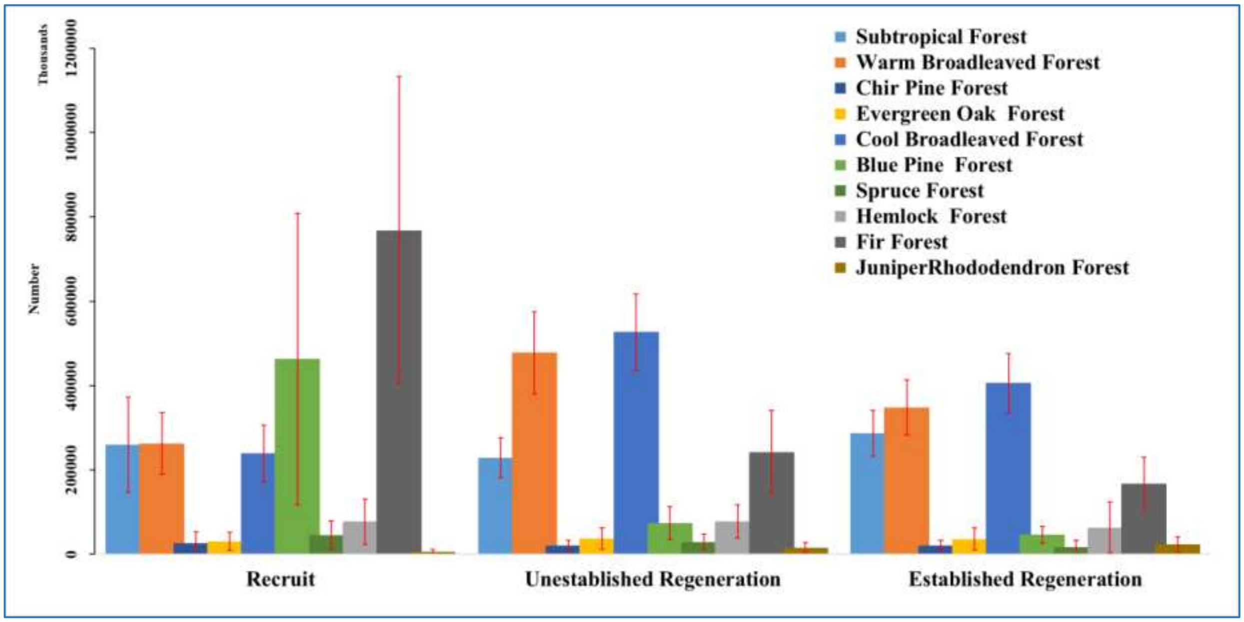


Figure 8.2 Total Regeneration by Forest Type

8.3.2 Regeneration by Elevation

Table 8.7 show the regeneration density across different elevation range. The elevation range of =>4000 *m.a.s.l* recorded the smallest density of recruits (56) while the greatest density of recruits (1,252) is recorded at 3000-4000 *m.a.s.l.* However, the greatest number of established regenerations is recorded at an elevation range of 0-1000 *m.a.s.l* (816) while the elevation range of 2000-3000 recorded the greatest unestablished regeneration (788).

Table 8.7 Regeneration per ha by Elevation

Elevation (m.a.s.l)	Recruits		Unestablished Regeneration		Established Regeneration	
	No. ha^{-1}	MoE (%)	No. ha^{-1}	MoE (%)	No. ha^{-1}	MoE (%)
0-1000	711	44	640	21	816	19
1000-2000	432	26	647	19	465	16
2000-3000	910	52	788	16	561	19
3000-4000	1252	42	484	31	421	27
=>4000	56	169	241	102	324	114

The total number of regenerations show a similar trend with the elevation range of 2000-4000 *m.a.s.l* recording the greatest number of recruits (Figure 8.3). The smallest number of regenerations is recorded at an elevation range of =>4000. This elevation range mainly constitutes the Juniper Rhododendron Forest, upper parts of Fir Forest and consist mainly of Juniper, Rhododendron, Salix, Sorbus and a few Fir trees.

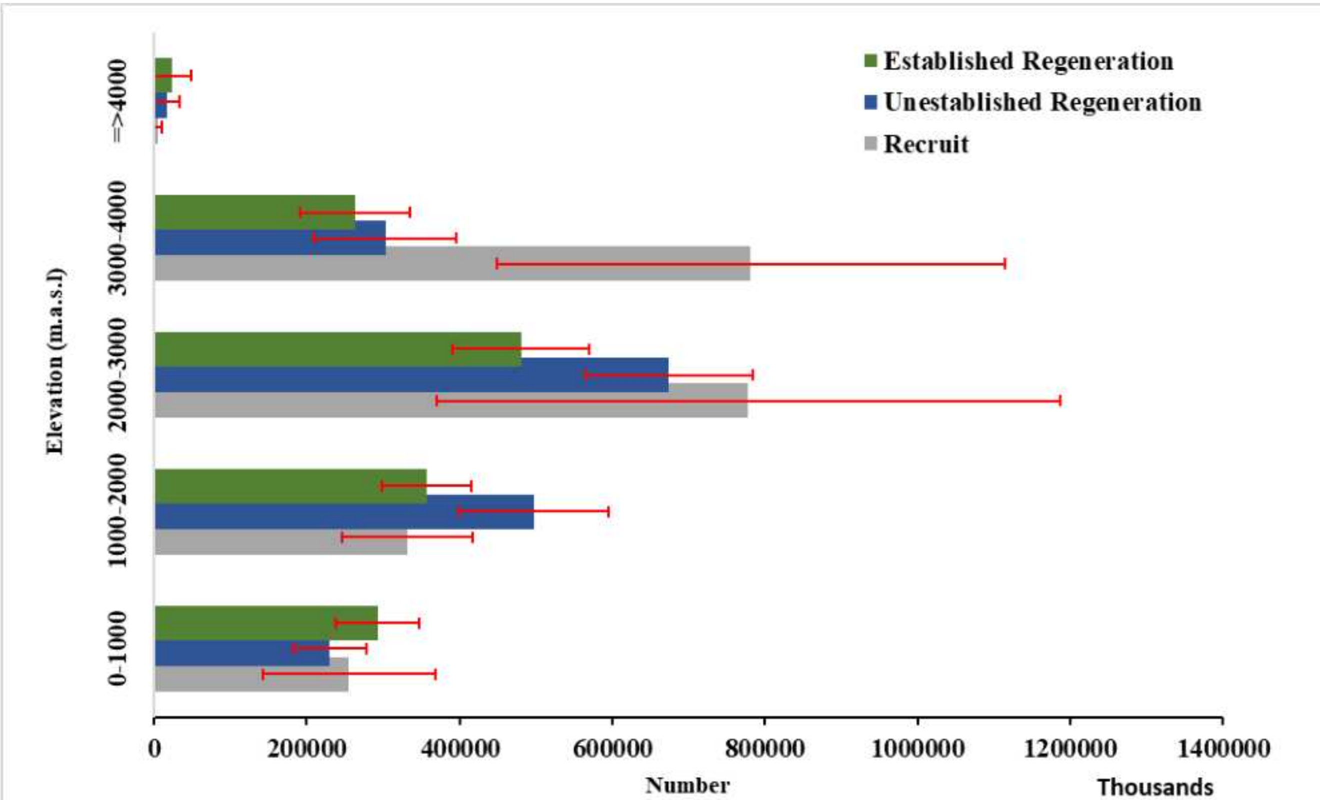


Figure 8.3 Total number of recruits by Elevation

8.3.3 Regeneration by Species

The regeneration density and number of total regenerations for different species are reported in Table 8.8 and Table 8.9. Regeneration was observed for 28 species from the 31 major species reported in this *report*. The rest of the species are clubbed into "*Ohers*". From the species reported, Blue Pine has the greatest density (200 ha^{-1}) and total number (534 million) of recruits and *Symplocos* spp. has the greatest estimates for unestablished regeneration (density of 69 No. ha^{-1} & total No. of 185 million). *Rhodendron* spp. has the greatest estimates of established regeneration (65 no ha^{-1} & a total estimate of 173 million) and a comparable number of unestablished regeneration (59 no ha^{-1} & 158 million).

Table 8.8 Regeneration per ha by Species

Species	Recruits		Unestablished Regeneration		Established Regeneration	
	No. ha^{-1}	MoE (%)	No. ha^{-1}	MoE (%)	No. ha^{-1}	MoE (%)
Abies densa	118	53	26	51	12	43
Acer spp.	43	48	24	40	12	46
Alnus spp.	1	158	2	130	3	129
Aphanamixis polystachya	1	122	1	158	4	78
Beilschmiedia spp.	5	72	6	56	5	55
Betula spp.	2	88	2	86	8	99
Bombax ceiba	1	149	1	141	1	141
Castanopsis spp.	13	60	31	38	24	67
Duabanga grandiflora	-	-	1	200	1	200
Engelhardia spicata	1	94	3	84	3	78
Exbucklandia populnea	-	-	-	-	1	200
Juglans regia	-	-	-	-	1	200
Juniperus spp.	5	93	5	73	5	62
Larix griffithii	1	200	2	159	1	200
Magnolia spp.	-	-	1	200	1	200
Persea spp.	19	88	35	40	23	34
Phoebe goalparensis	-	-	1	200	1	200
Picea spinulosa	8	65	6	60	4	72
Pinus roxburghii	4	71	5	101	4	112
Pinus wallichiana	200	74	25	62	12	52
Quercus spp.	38	53	49	36	27	32
Rhododendron spp.	97	96	59	30	65	34
Schima wallichii	4	87	8	73	5	59
Sterculia villosa	-	-	2	93	1	141
Symplocos spp.	41	35	69	27	49	31
Taxus baccata	-	-	1	149	-	-
Toona ciliata	1	200	-	-	1	200
Tsuga dumosa	17	69	18	84	7	110
Other	188	29	276	13	271	13

Table 8.9 Total Regeneration by Species

Species	Recruits		Unestablished Regeneration		Established Regeneration	
	Number	MoE (%)	Number	MoE (%)	Number	MoE (%)
Abies densa	315,207,703	53	68,430,438	51	30,366,007	43
Acer spp.	113,337,912	48	63,725,845	40	29,510,626	46
Alnus spp.	1,710,761	158	4,276,902	130	7,698,424	129
Aphanamixis polystachya	1,710,761	122	1,710,761	158	8,126,114	78
Beilschmiedia spp.	12,403,017	72	13,686,088	56	12,403,017	55
Betula spp.	5,132,283	88	3,849,212	86	20,956,822	99
Bombax ceiba	1,283,071	149	855,380	141	855,380	141
Castanopsis spp.	33,359,838	60	82,544,215	38	63,725,845	67
Duabanga grandiflora	-	-	1,283,071	200	1,710,761	200
Engelhardia spicata	2,566,141	94	7,698,424	85	7,698,424	78
Exbucklandia populnea	-	-	-	-	427,690	200
Juglans regia	-	-	-	-	427,690	200
Juniperus spp.	11,119,946	93	11,975,327	73	13,258,397	62
Larix griffithii	2,138,451	200	3,849,212	159	427,690	200
Magnolia spp.	-	-	1,283,071	200	855,380	200
Persea spp.	48,328,997	88	92,381,091	40	60,732,013	34
Phoebe goalparensis	-	-	855,380	200	855,380	200
Picea spinulosa	19,673,751	65	13,686,088	60	8,126,114	72
Pinus roxburghii	9,409,185	71	11,975,327	101	9,836,875	112
Pinus wallichiana	34,185,104	74	65,864,296	62	30,793,697	52
Quercus spp.	100,507,205	53	129,162,451	36	70,996,579	32
Rhododendron spp.	257,897,212	96	157,817,697	30	172,786,855	34
Schima wallichii	8,126,114	87	20,101,441	73	11,975,327	59
Sterculia villosa	-	-	3,421,522	93	855,380	141
Symplocos spp.	109,488,700	35	184,334,491	27	129,162,451	31
Taxus baccata	-	-	1,283,071	149	-	-
Toona ciliata	427,690	200	-	-	427,690	200
Tsuga dumosa	44,907,475	70	47,901,306	84	17,107,609	110
other	501,680,646	29	736,910,275	13	722,796,497	13

8.3.4 Discussion

Regeneration is important for sustenance and is an indicator of forest health and vitality (FAO, 2019). The NFI takes stock of regeneration through the accounting of three types of regeneration; recruits, unestablished and established regeneration. This gives an overall picture of the regeneration status in Bhutan. However, the Department conducts regeneration surveys at a smaller scale during the forest management and operational inventory for a better understanding of the growth and need for restocking to improve the survival of regeneration.

Forest recorded a greater number of regeneration than Non-Forest area with 798±198, 647±67 and 536±53 No. ha^{-1} of recruits, unestablished and established regeneration respectively. The number of recruits and unestablished regeneration are comparable to the results from the 1st NFI (746±169 and 674±101 respectively) while the number of established regenerations has decreased considerably in the 2nd NFI. The 1st NFI reported a total established regeneration of 1,240±155 No. ha^{-1}.

Coniferous Forest contributes significantly to the overall regeneration density of the Forest with 1,640±634 No. ha^{-1} compared to 446±88 No. ha^{-1} recorded for Broadleaved Forest. Blue Pine Forest has the greatest No. of recruits (4,477±3,344 No. ha^{-1}) while the greatest number of recruits in Broadleaved Forest is recorded in Evergreen Oak Forest (740±541). This is in line with the highest density of recruits recorded in Bumthang (4,1,48±2,711); a Dzongkhag predominantly covered by Blue Pine and other Conifer Forests.

Similarly, the Broadleaved Forest (699±79) recorded a greater number of unestablished regeneration than the Coniferous Forest (522±129). The greatest number of unestablished regeneration (919±644 No. ha^{-1}) in the Evergreen Oak Forest contributed significantly to the overall unestablished regeneration in Broadleaved Forest. Similarly, *Symplocos spp* and *Quercus spp* showed the greatest number of unestablished regenerations at the species level. Regeneration in Broadleaved Forest is a challenge in Bhutan and has been attributed to many causes; grazing being one of them (Wangda & Ohsawa, 2006). Controlled grazing and assisted regeneration through plantation, gap filling and maintenance are undertaken by the Department mostly in the Broadleaved Forest. Buffum et al., 2009a reported an increase in natural regeneration with decreasing number of cattle grazing in Broadleaved Community Forest in Bhutan. Accordingly, the Broadleaved Forest (598±63) also recorded a greater density of established regeneration than the Coniferous Forest (387±97). Evergreen Oak Forest and Sub-Tropical Forest recorded a density of 892±645 and 805±152 respectively for established regeneration. This is in the range of seedling density of 520-1240 Ind/ha reported by (Ballabha et al., 2013) in the Sub-tropical forest in Alaknanda Valley, Garhwal Himalaya.

While the greater number of recruits in the Coniferous Forest is indicative of stable stands, the density of recruits in the Broadleaved Forest is in the lower range of the density in Bhutan and the average range reported in the region. However, the Broadleaved have greater number of established regenerations including the per ha estimates. Therefore, a focused and area specific regeneration survey is recommended at a smaller management level, and appropriate management activities/interventions should be prescribed in the *Code* for successful regeneration. Similarly, monitoring of regeneration in the Coniferous Forest should also be done to improve the overall forest stand in Bhutan.

SPECIES DIVERSITY

9 SPECIES DIVERSITY

9.1 Introduction

Bhutan is a small Himalayan country (38,394 km^2) with elevations ranging from about 130 *m.a.s.l* in the foothills to over 7,500 *m.a.s.l* in the North; within a distance of 170 km from the extreme north to the south (DoFPS, 2019) . These provide a conducive environment and climate to diverse forest and other biological diversity, positioning Bhutan as a part of the Himalayan global biodiversity hotspot (Mittermeier et al., 2004). Similarly, for the NFI, data were collected from 1,969 accessible CP wherein the elevation of the accessible plots ranged from 150 *m.a.s.l* to 5590 *m.a.s.l*, hence, ensuring diversity both at the plot level and along the gradient.

Diversity in simple terms may be referred to as: (i) richness; referring more to the count of the individual in the plot or the study area; and (ii) evenness; indicating the relative abundance of various species in a sample. Many indices and concepts were introduced to understand and describe diversity and accordingly, this report shall explore alpha diversity, beta diversity and gamma diversity to understand diversity. Whittaker (1977) explained the concept in simpler terms; alpha diversity (within-habitat diversity), beta diversity (among-habitat differentiation in a landscape) and gamma diversity (total within-landscape diversity) (Tuomisto, 2010). This is further described using the diversity indices such as Species richness, Shannon index, Simpson's index, and Evenness, which are commonly used diversity indices (Hill, 1973; Oksanen, 2017).

9.1.1 Gamma Diversity

Species richness is the most common measure of diversity and is measured by simply counting the number of individuals in the landscape, Bhutan and Bhutan's Forest in this context. This is reported as the "observed" value under Gamma Diversity. However, since it is a sampling procedure, it is not possible to record all the species present. The total species including the unseen species are estimated using *jackknife* estimators and accordingly, variance is estimated based on the number of species occurring only once in the data ("*singletons*") (Oksanen, 2017) . These have been reported as "extrapolated" in the report.

9.1.2 Alpha Diversity

Alpha diversity is the within-habitat diversity or in our case, the within plot diversity. Like the Gamma diversity at the National level, alpha diversity measures the richness at the plot level. However, Whittaker, 1972 also recommended taking into account slope measurements through the Simpson index and the Shannon-Weiner index. For this report, Shannon-Weiner index and Pielou's Evenness are estimated and reported for different categories.

9.1.2.1 Shannon Index (H)

The Shannon index H is a measure of species richness (S) in particular site (plot) and how evenly distributed species abundance is at each site. *H* is estimate using equation (9.1).

$$\mathrm{H} = -\sum_{i=1}^{S} p_i \, x \, log \, p_i \tag{9.1}$$

Where,

H is Shannon index;
S is number of species; and
p_i is the proportion of species i.

H value ranges between 1.5 to 3.5, with a value of 0 indicating that the area has only one species. Increasing value of H indicates increasing diversity.

9.1.2.2 Pielou's Evenness *J*

Pielou's Evenness *(J*) indicates how evenly the species are distributed in the forest with values ranging from 0 to 1. A value of 0 indicate no evenness and 1 indicate complete evenness. *J* is estimated calculated using equation (9.2).

$$J = \frac{H}{\log(S)} \tag{9.2}$$

Where;
J is Pielous Evenness;
H is Shannon index; and
S is number of species.

9.1.3 Beta Diversity

Beta diversity is the extent of differentiation of communities along habitat gradients and expresses the relative dissimilarity. Over the year, various methods or procedures have been developed to measure beta diversity. This report shall use the beta index for the Whittaker's species turnover and the Sorenson index of dissimilarity using equation (9.3) and equation (9.4) respectively.

$$\beta_w = S/\bar{\alpha} \; -1 \tag{9.3}$$

$$\beta_s = \frac{b+c}{(2a+b+c)} \tag{9.4}$$

Where,
β_w is the Whittaker's species turnover;

S is the total number of species in a collection site;
$\bar{\alpha}$ is the average richness per one site;
βs is the Sørensen index of dissimilarity;
a is the number of shared species in two sites; and
b and c are the numbers of species unique to each site.

While the β_w is based on the ratio of gamma diversity and the alpha diversity, βs computes the diversity from pairwise comparison of sites (Oksanen, 2017; Vellend, 2001). The value of βs ranged from 1 to 0, where 1 indicated no shared species and 0 mean the same species composition (Hao et al., 2019).

9.2 Measure of Species Diversity by Different Categories

Species Diversity shall be discussed first at the National level and segregated into Forest and Non-Forest, after which diversity measured at the CP level falling in Forest shall be discussed in various categories.

9.2.1 Species Diversity by Land Area

Table 9.1 shows the diversity estimates in Bhutan. The NFI recorded a total of 710 unique species in Bhutan while the Forest recorded 701 unique species and the Non-Forest saw 208 unique species. Similarly, the number of species can be extrapolated to 824±23, 815±23 and 307±29 for the National, Forest and Non-Forest to account for the unseen species as a result of the inaccessibility of plots, 1597 unknown samples and for species outside the accessible sample plots missed because of the sampling methodology adopted. Further, the Forest stand is more diverse than the Non-Forest with an H value of 1.75 compared to an H value of 0.61 for the Non-Forest; and also more evenly distributed with *J* values of 0.74 in comparison to the Non-Forest value of 0.65.

Table 9.1 Species diversity by Land Area

Class	Gamma Diversity		Alpha diversity		Beta diversity	
	Observed	Extra-polated	Shannon index *(H)*	Pielou's Evenness *(J)*	Sorenson dissimilarity index*(βs)*	Whittaker's turnover (β_w)
Bhutan	710	824	1.72	0.73	0.94	67
Forest	701	815	1.75	0.74	0.93	65
Non-Forest	208	307	0.61	0.65	0.98	81

Non-Forest has a greater value of the βs (0.98) given the spread and uniqueness in relation to the Forest Plot (0.93). The greater βw in Non-Forest (81) also indicates greater turnover than in Forest (65). This is evident from the species accumulation curve (sac) shown in Figure 9.1. The sac was developed using Kindt's exact method. The number of observed species increases exponentially to 500 sites, after which the rate of observation of new species decreases slowly moving towards a static position. The number of new species observed increased almost proportionally to the number of sites and hence the higher *βw* in Non-Forest.

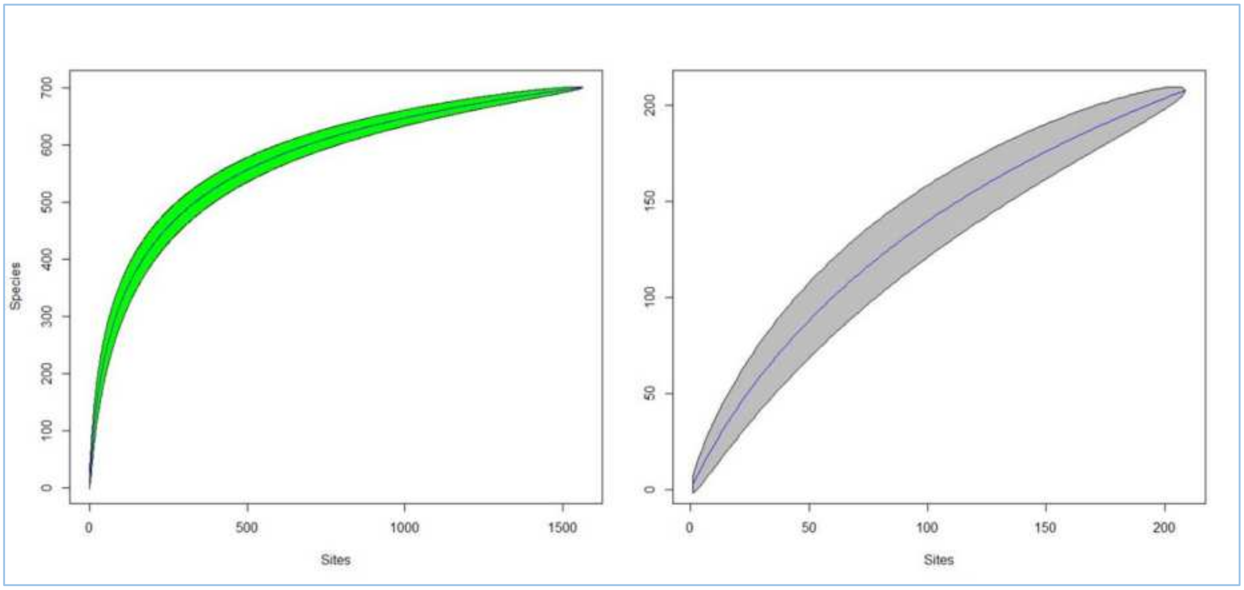


Figure 9.1 Species accumulation curve for Forest(left) and Non-Forest (right)

9.2.2 Species Diversity by Dzongkhag

Table 9.2 shows the diversity estimates of the Forest by Dzongkhag. The number of observed species ranges from 44 (Paro) to 357 (Zhemgang) which is extrapolated to 58 and 477 to include the unseen species. Tsirang, the smallest Dzongkhag has a high species number of 198 observed and 291 extrapolated gamma diversity.

Table 9.2 Species diversity by Dzongkhag

Dzongkhag	Gamma Diversity		Alpha diversity		Beta diversity	
	Observed	Extra-polated	Shannon index *(H)*	Pielou's Evenness *(J)*	Sorenson dissimilarity index*(βs)*	Whittaker's turnover (β_w)
Bumthang	73	96	1.16	0.64	0.79	11
Chhukha	259	342	1.83	0.77	0.93	23
Dagana	335	444	2.19	0.80	0.91	21
Gasa	50	72	1.06	0.69	0.86	10
Haa	143	201	1.52	0.71	0.87	16
Lhuentse	149	207	1.56	0.73	0.88	16
Mongar	203	290	1.61	0.72	0.90	21
Paro	44	58	1.07	0.67	0.79	8
Pemagatshel	228	319	2.16	0.79	0.86	14

Punakha	108	142	1.62	0.74	0.86	11
Samdrup Jongkhar	302	399	2.13	0.81	0.91	21
Samtse	189	262	1.80	0.76	0.91	17
Sarpang	301	404	2.19	0.82	0.87	20
Thimphu	55	66	1.09	0.61	0.90	8
Trashigang	215	293	1.59	0.70	0.83	21
Trashi Yangtse	133	184	1.64	0.74	0.89	13
Trongsa	188	259	1.83	0.77	0.89	16
Tsirang	198	291	1.94	0.76	0.93	15
Wangdue Phodrang	266	374	1.55	0.71	0.91	29
Zhemgang	357	477	2.21	0.82	0.89	23

Zhemgang and Tsirang have a greater value on the alpha diversity; H index of 2.21 and 2.19 respectively while both the Dzongkhags has a *J* value of 0.82. Gasa and Paro has the lowest density with a H index of 1.06 and 1.07 respectively. Tsirang and Chukha has greater *βs* of 0.93. Paro and Bumthang have a *βs* of 0.79 which also indicates fewer shared species on a general scale of 0 to 1 compared to other Dzongkhags. Wangdue has the highest *βw* of 23 while Thimphu and Paro have a *βw* value of 8 each. The pictorial representation of the same is shown in Figure 9.3.

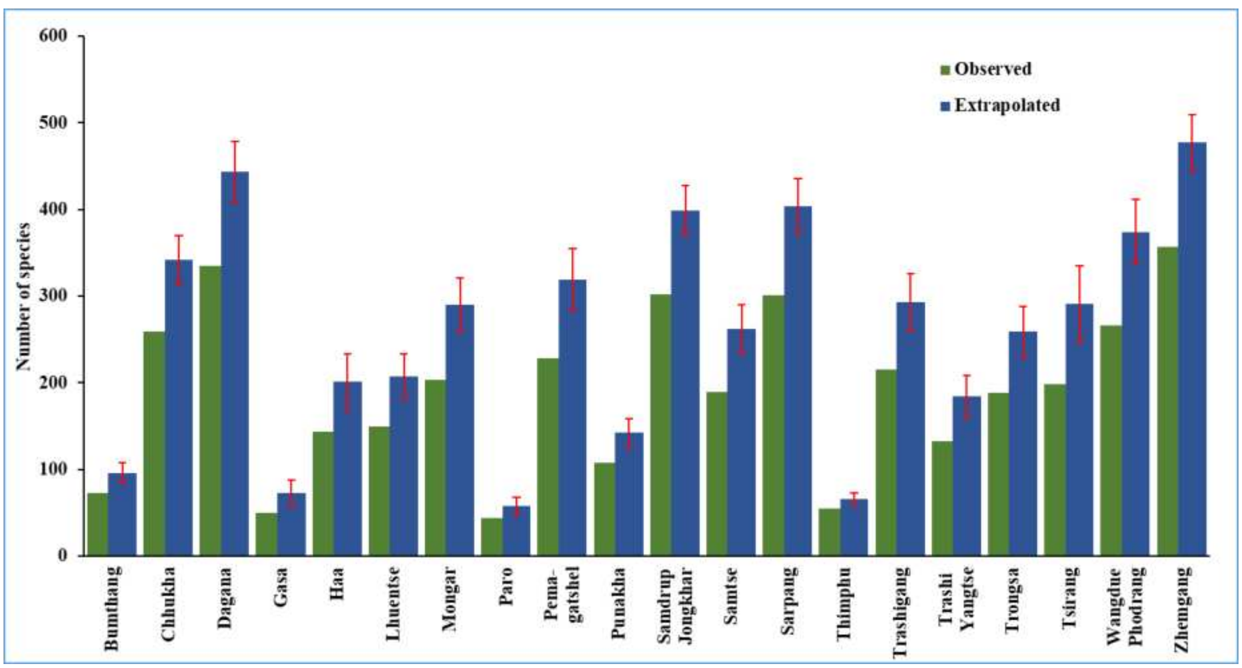


Figure 9.2 Gamma diversity by Dzongkhag

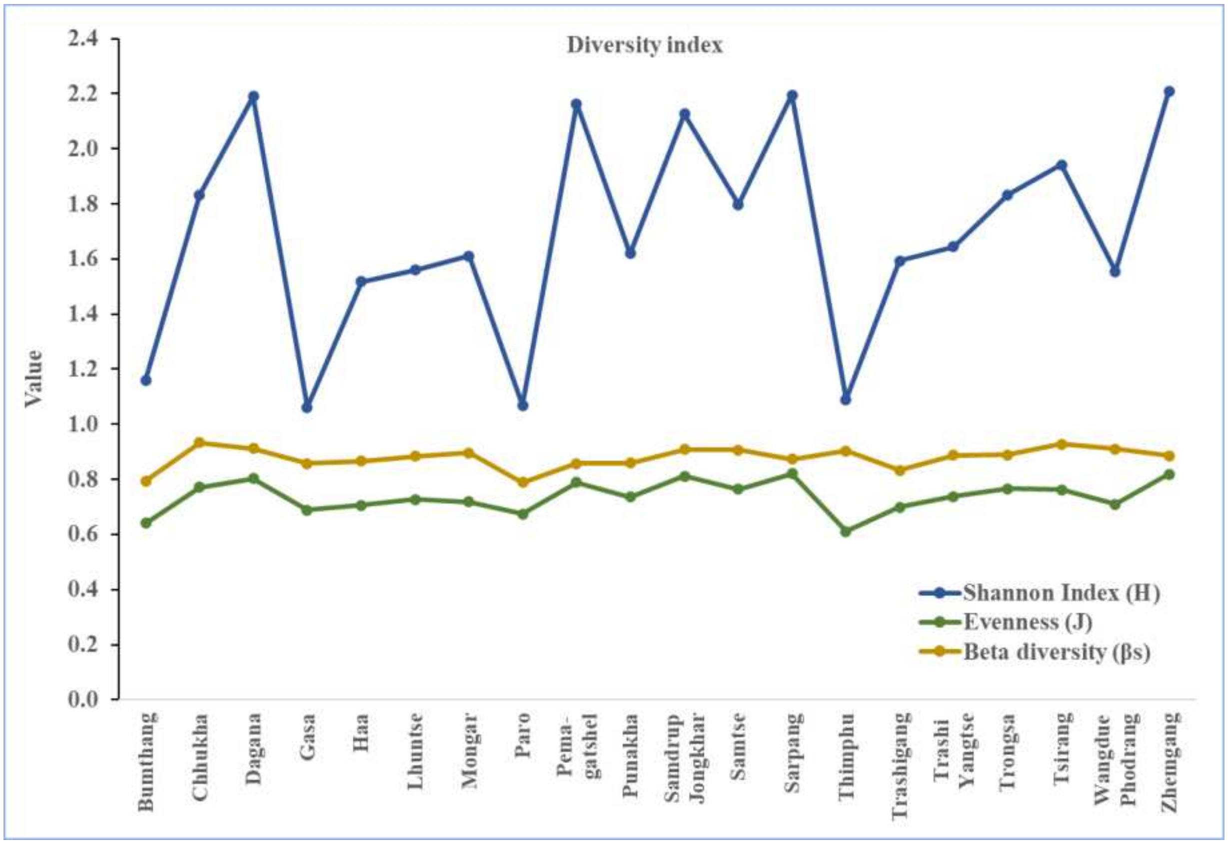


Figure 9.3 Alpha and Beta diversity index by Dzongkhag

9.2.3 Species Diversity by Forest Type

Broadleaved Forest recorded a total of 678 species while the Coniferous Forest recorded 192 species. Similarly, it is extrapolated to 792 and 260 respectively using the *jacknife* estimator. Further, Broadleaved Forest indicates greater diversity with a greater H and *J* value of 2.01 and 0.79 respectively. Both the Forest Class ranks high in the *βs* while Broadleaved Forest has a comparatively greater *βw* turnover rate at 52 over 33 in Coniferous Forest.

Table 9.3 Species diversity by Forest Class

Class	Gamma Diversity		Alpha diversity		Beta diversity	
	Observed	Extra-polated	Shannon index *(H)*	Pielou's Evenness (*J*)	Sorenson dissimilarity index*(βs)*	Whittaker's turnover (β_w)
Broadleaved Forest	678	792	2.01	0.79	0.92	52
Coniferous Forest	192	260	1.10	0.64	0.85	33

The observed species ranged greatly among the Forest Types; Warm Broadleaved Forest has the greatest observed species at 524 while the smallest number of species was observed in Juniper Rhododendron Forest (47) (Figure 9.4)

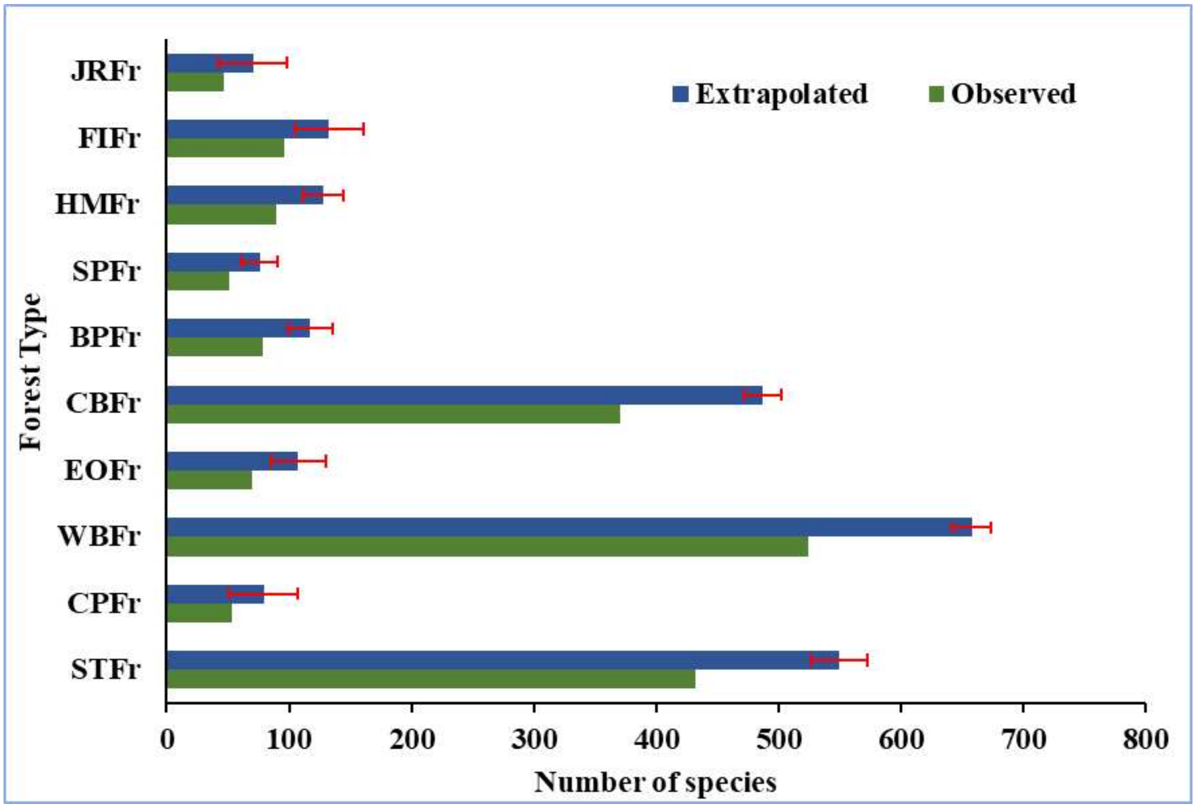


Figure 9.4 Gamma diversity by Forest Type

Subtropical Forest ranks high in diversity with an H of 2.2 and a *J* value of 0.90. Chir Pine Forest, on the other hand, is the least diverse among the Forest Types in Bhutan with an H value of 0.58 and a *J* value of 0.46. Chir Pine also has the smallest *βs* of 0.59 indicating a greater number of shared species compared to other Forest Types. Warm Broadleaved Forest has the greatest *βs* of 0.91 and a *βw* of 38 while Spruce has the smallest *βw* of only 6 (Table 9.4).

Table 9.4 Species diversity by Forest Type

Forest Type	Gamma Diversity		Alpha diversity		Beta diversity	
	Obser-ved	Extra-polated	Shannon index (*H*)	Pielou's Evenness (*J*)	Sorenson dissimilarity index(*βs*)	Whittaker's turnover (β_w)
Subtropical Forest	432	550	2.20	0.81	0.90	28
Chir Pine Forest	53	79	0.58	0.46	0.59	14

Warm Broadleaved Forest	524	658	2.08	0.80	0.91	38
Evergreen Oak Forest	70	107	1.41	0.70	0.83	8
Cool Broadleaved Forest	371	487	1.88	0.78	0.84	32
Blue Pine Forest	79	117	0.94	0.57	0.65	14
Spruce Forest	51	76	1.43	0.72	0.71	6
Hemlock Forest	90	128	1.61	0.75	0.73	9
Fir Forest	96	133	1.21	0.68	0.69	15
Juniper Rhododendron Forest	47	71	0.61	0.53	0.83	14

9.2.4 Species Diversity by Elevation

Table 9.5 shows the diversity in the different elevation class defined for the purpose of the NFI. The greatest number of species is observed and hence extrapolated in the elevation class of 1000-2000 (525 and 659 respectively) while the smallest is recorded at an elevation >=4000 *m.a.s.l*. Similarly, the turnover of new species is greatest in the 1000-2000 *m.a.s.l* and the smallest >=4000 *m.a.s.l* with a *βw* value of 78 and 20 respectively.

Table 9.5 Species diversity by Elevation

Elevation *(m.a.s.l)*	**Gamma Diversity**		**Alpha diversity**		**Beta diversity**	
	Obser-ved	**Extrapol-ated**	**Shannon index *(H)***	**Pielou's Evenness *(J)***	**Sorenson dissimilarity index*(βs)***	**Whittaker's turnover (β_w)**
<1000	443	562	2.15	0.81	0.91	61
1000-2000	525	659	1.97	0.77	0.91	78
2000-3000	383	502	1.77	0.75	0.86	62
3000-4000	128	175	1.26	0.69	0.78	31
>=4000	48	83	0.48	0.44	0.82	20

The elevation <1000 has high H and *J* values of 2.15 and 0.18 respectively indicating a higher diversity and more evenly distributed landscape. The lowest diversity was observed above >=4000 m.a.s.l with H and *J* values of 0.48 and 0.44 respectively. In addition, the Sub-tropical Forest found in the elevation class <1000 also recorded the greatest *βs* of 0.91 showing great dissimilarity and hence more diversity. The elevation 1000-2000 *m.a.s.l* also showed a *βs* of 0.91 while the least *βs* of 0.78 was recorded for the elevation class of 3000-4000 *m.a.s.l*. (Figure 9.5)

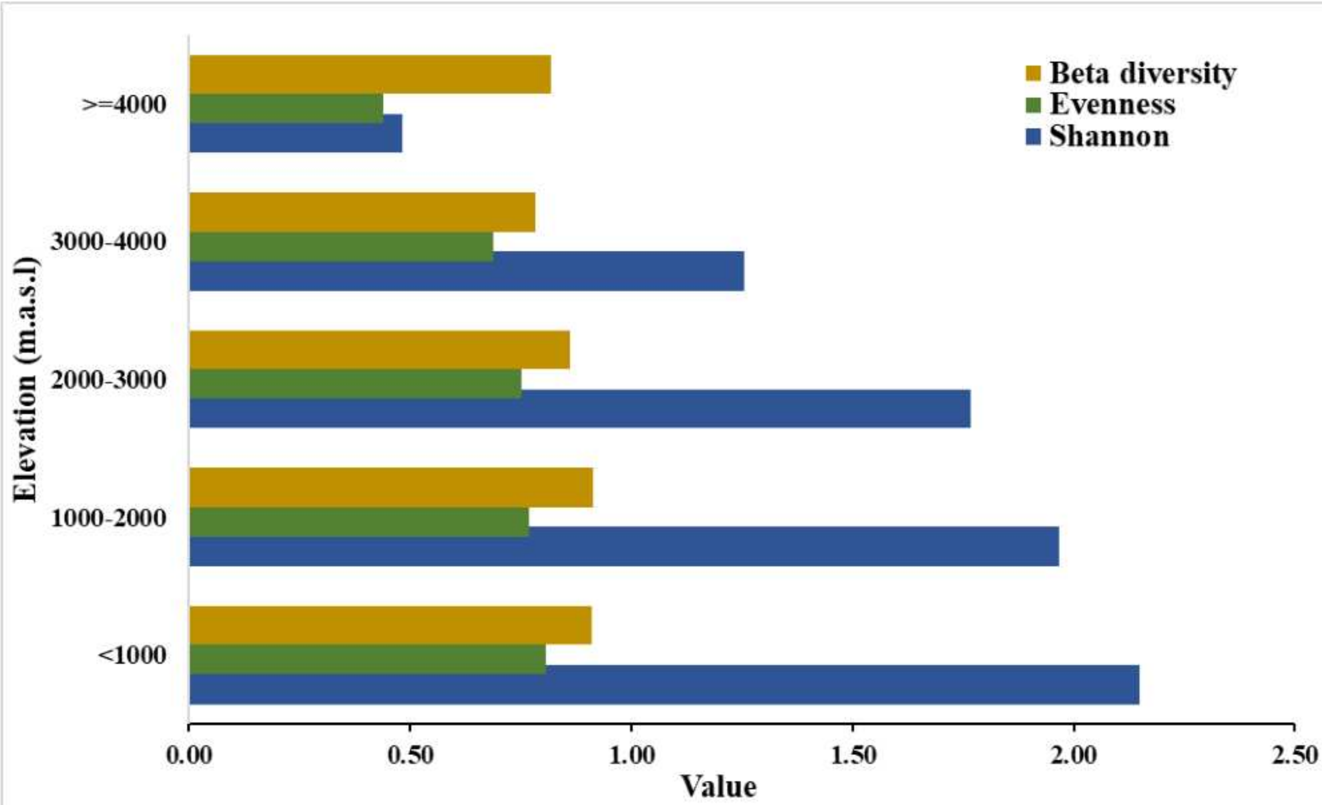


Figure 9.5 Alpha and Beta diversity by Elevation

9.3 Discussion

Bhutan has a high number of species 710 (824±23) for a small country, from which 701 (815±23) are observed in the Forest. The unknown tree samples have decreased considerably in the 2nd NFI; 1,597 unknown tree counts were recorded from the total 83,306 individual trees during the NFI compared to a total of 1,968 unknown species of 51,116 individual trees recorded previously (FRMD, 2018b). Techniques and precautions were put in place to help identify the unknown species and to increase plot accessibility based on the learning from the 1st NFI and accordingly, the number of observed species has increased.

Further, Bhutan's Forest recorded an H value of 1.75, which is higher than the H value observed in the 1st NFI. Tenzin & Hasenauer (2016) recorded a H value of 1.73±0.62 in their study in the Broadleaved Forest in Bhutan while studies of 29 Forest types in India reported an H ranging from 0.28-1.75 (Sharma et al., 2010). Similar studies in the central Himalayan region recorded a H index ranging between 1.10 and 2.31 and species evenness ranging between 0.46 to 0.90 (Joshi et al., 2022).

Forest in Bhutan are evenly distributed with a *J* value of 0.74 indicating moderately high evenness while the Non-Forest has a *J* value of 0.65 indicating moderate evenness. The highest H and *J* value was recorded for Zhemgang Dzongkhag at 2.21 and 0.82 respectively. Zhemgang has a high forest cover with 93 % of the Dzongkhag area and is predominantly covered with Broadleaved Forest, which is more diverse than the Coniferous Forest as indicated by the indices described in Table 9.3.

Subtropical Forest has an H value of 2.20; the greatest amongst all the Forest types. Comparison amongst the various Forest Types shows that Chir Pine Forest has a lower H (0.58), *J* (0.46) and βs (0.59) indicating fewer diversity than the Subtropical and Warm Broadleaved Forest with the higher values. The Juniper Rhododendron Forest is also low in diversity with the H, J and βs close to the Chir Pine Forest. This is because Chir Pine is xerophytic/ gregarious in nature and usually occurs as a pure stand on drier valleys making it difficult for other forest tree species to coexist (DoFPS, 2021b, 2021c; Singh et al., 2017) . Studies in a small patch of Chir Pine Forest in Bhutan reported H and *J* value for 0.83 and 0.06 (Mukhia et al., 2011). Arya & Ram, 2019 reported an H value ranging from 0.69 to 0.89 in Chir Pine Forest and 1.71-2.11 in Mixed Broadleaved Forest in Central Himalaya in addition to an evenness index ranging between 0.12-0.21 in Chir Pine Forest and 0.21-0.43 in Warm Broadleaved Forest. The Warm Broadleaved Forest and Subtropical also recorded a greater βs of 0.9 showing higher dissimilarity and diversity. Warm Broadleaved Forest also has a βw f 38, the highest turnover amongst all Forest Type.

The elevation range <1000 *m.a.s.l* showed the greatest diversity with H (2.15), *J* (0.81) and βs (0.92). This is predominantly Subtropical Forest which has high diversity indices as described above. However, the βw is higher in the elevation range 1000-2000 *m.a.s.l* with a turnover of 78 species. This elevation also recorded 525 species. Unlike the elevation range of <1000 *m.a.s.l*, the 1000-2000 *m.a.s.l* elevation range house many Forest Types depending on the topography, soil and climatic condition. Warm Broadleaved Forest and Chir Pine Forest dominates these elevation range while part of the Sub-tropical Forest impeded in the lower range and the Evergreen in the upper ranges of the 1000-2000 elevation class.

FOREST HEALTH AND DISTURBANCE

10 FOREST HEALTH AND DISTURBANCE

10.1 Introduction

Forest cover has decreased over the two NFIs. The 1st NFI reported a forest cover of 71.13 % which has decreased to 69.71 %. Deforestation and forest degradation in the form of timber harvesting, pest and disease, and allotment of land for development activities are important reasons as discussed in the proceeding chapters. This is a serious concern especially when the Forest Resources Potential Assessment 2013 recommends only 11.27% of the total geographical area to be economically potential for sustainable forest management. Burger (2004) describes a healthy forest as a resilient forest that is free of pest and diseases, and which grows "*a rate commensurate with the local climate, geographic position, and soil resource to complete their life cycles".* A healthy forest may mean different things to different people and is discussed thoroughly in Concept of forest health: utilitarian and ecosystem perspectives" (Kolb & Covington, 1994). Therefore, a proper understanding of forest health and disturbance is key to sustainable forest management.

Generally, Forest disturbances disrupt the forest ecosystem resulting in mortality (DoFPS, 2021d) and migration of species, and an impediment to other zones. Therefore, understanding the growing stock and other traditional forest parameters, a better and more in-depth understanding of forest disturbances in relation to forest health is important. While area specific-studies of the different types of forest disturbance are done regularly, the NFI provides holistic presence-absence data of evidence of forest disturbance information which are collected as per the methodology prescribed in Chapter II, Volume II of the Forest and Nature Conservation Code of Best Management Practices.

10.2 Timber Harvesting

Evidence of timber harvesting has been recorded for 634 plots in 330 cluster plots over the country (Figure 10.1). The records are restricted to the felling evidence within the plot only and extraction in the vicinity of the plot has not been considered. From the total timber evidence, about 95 % of the timber harvesting has been classified under selective felling, while 3% and 2% of the felling has been classified as clear felling and group selection system.

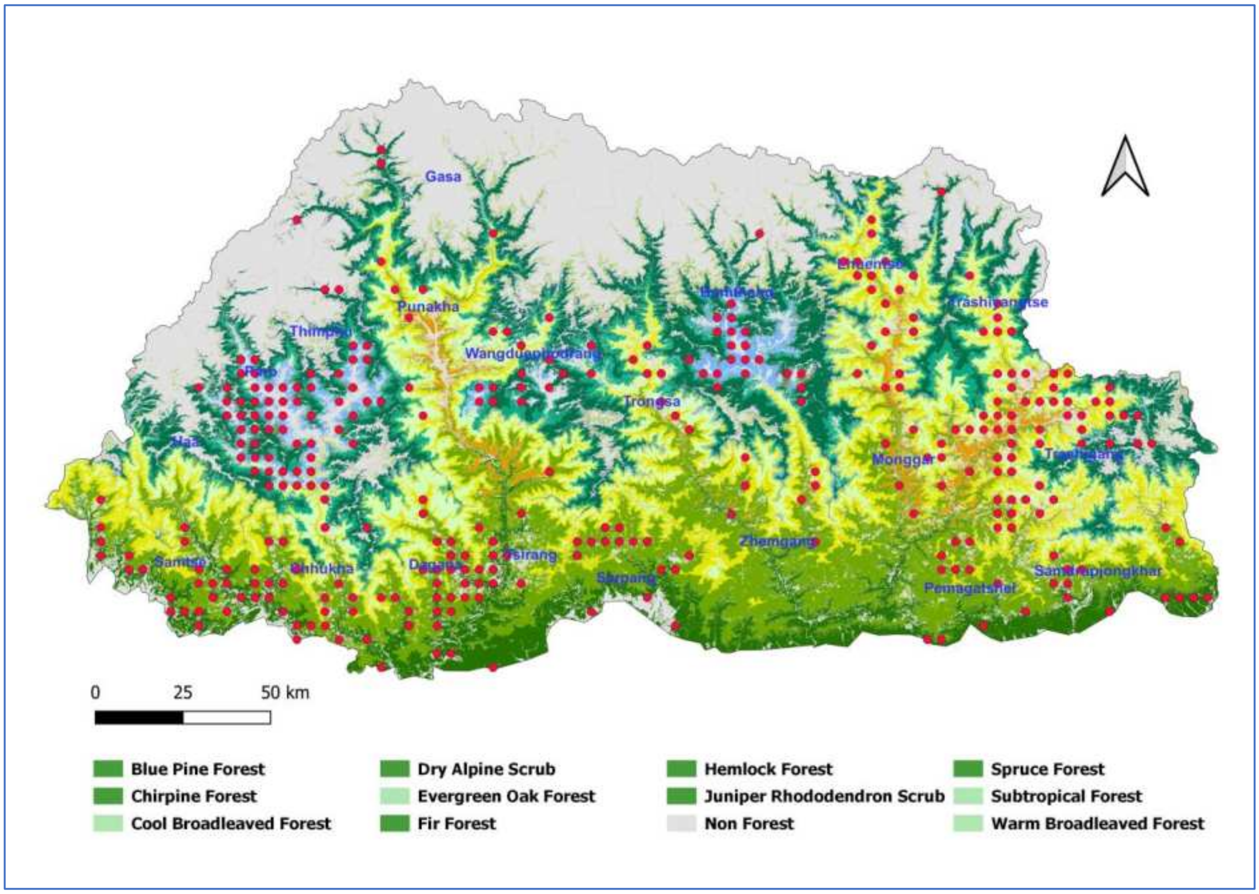


Figure 10.1 Timber extraction recorded in NFI plots

Timber harvesting is restricted near settlements, whereby the timber for rural house building and other uses are mainly allotted following the selection system, and group felling is mainly done for commercial harvesting in FMUs based on prescriptions defined in the *Code*.

10.3 Forest Pest and Diseases

Pest and disease have been detected in 742 plots (334 cluster plots) during the NFI. For the purpose of data collection, the pest and disease has been grouped broadly into; (i) Mistletoe, (ii) Fir dieback, (iii) Bark beetle and (iv) others.

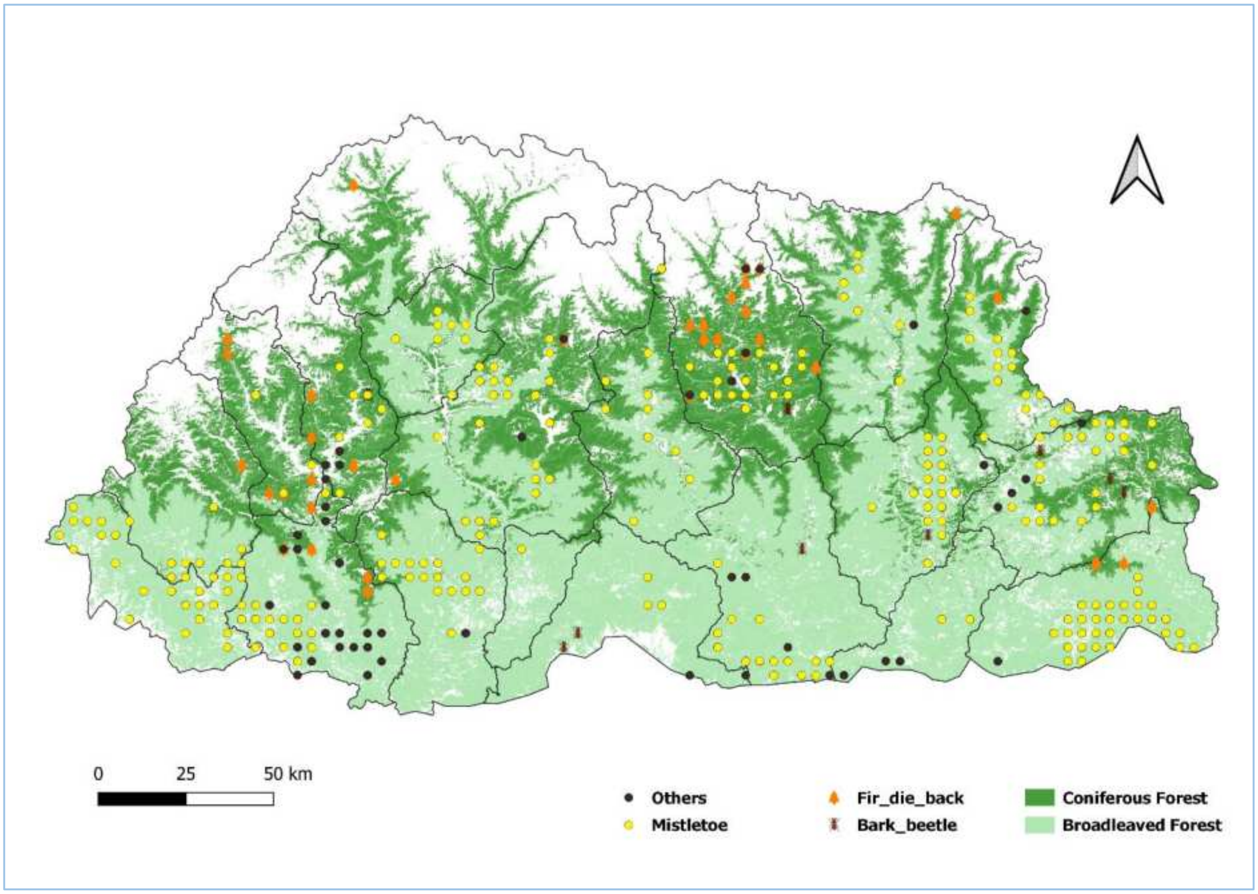


Figure 10.2 Evidence of different Pest and Disease in Bhutan

Mistletoe is the most widespread among the pest and disease; with 80 % of the total pest and disease recorded for the NFI (Figure 10.2 and Figure 10.3). These include dwarf mistletoe which accounts for 8.3 % of the total mistletoe detected. It is mostly recorded in Broadleaved Forest. Fir dieback is also observed more than the other pest and disease while bark beetle infestations are observed mostly in Blue Pine, Fir and other Conifer zones. Other infestations of pest and diseases such as dieback in other species, *Loranthu*s infestation etc., are included in “others”; with an infestation of 8 % of the total observed. The impact of pest and diseases on forest health and vitality, the importance of early detection, integrated pest management have been deliberated in Volume V of the Code. Therefore, it is important to carry out a detailed survey and accordingly, implement management activities prescribed by the *Code*.

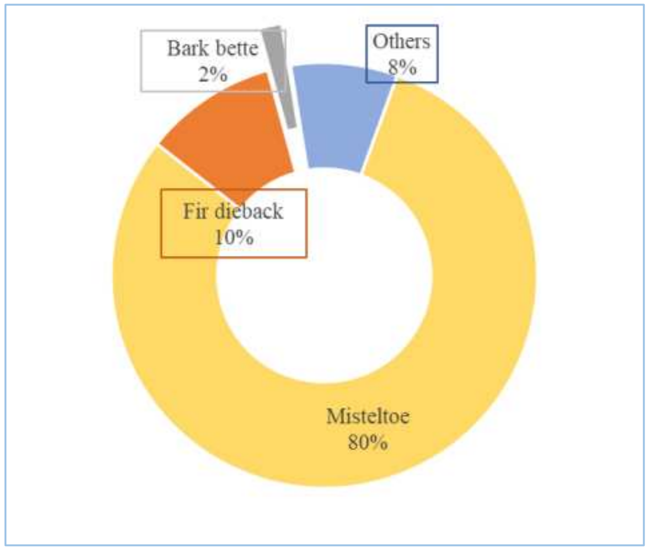


Figure 10.3 Percentage of evidence of different pest and diseases

10.4 Grazing

As an agrarian country with about 70 % in forest cover, grazing is a challenge for forest managers and livestock owners as well. While the cattle are grazed in *Tsamdro,* there are many incidences where cattle graze upon regeneration in the Forest. This was a serious issue especially in Broadleaved Forest and various authors have deliberated on the grazing management in Forests (Buffum et al., 2009b, 2009c; Darabant et al., 2007; Wangchuk et al., 2018). Evidence of cattle grazing was observed in 568 of the total accessible plots (1969). The plots are spread across Forest Types and elevation ranges (189 *m.a.s.l* to 5180 *m.a.s.l*) and 13 % of the plots show evidence of severe grazing. This shall seriously affect the regeneration success and proper management activities needs to be put in place to minimize grazing damages.

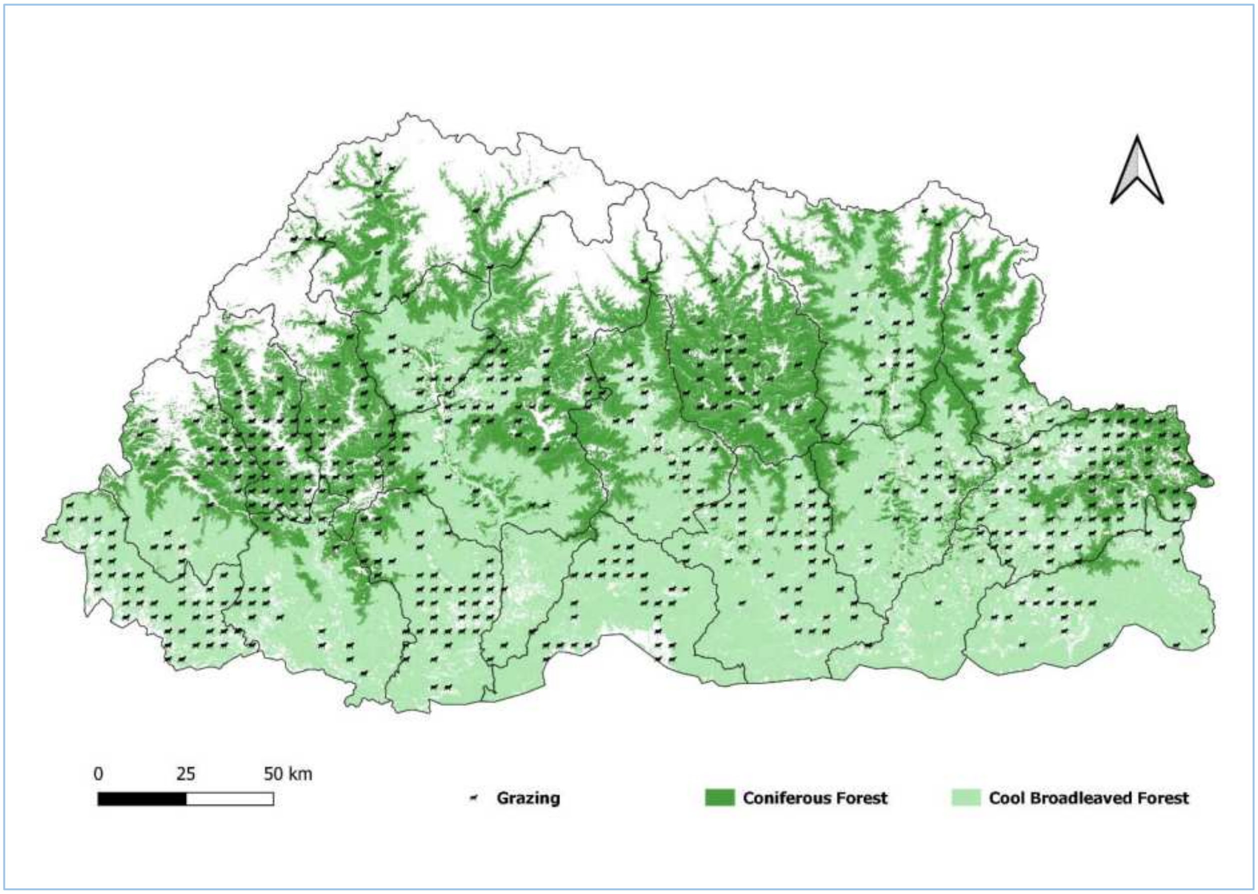


Figure 10.4 Evidence of Grazing in Forest plots

10.5 Forest Fire

Forest fire is one of the major forest disturbances and an annual phenomenon in Coniferous Forest, particularly Blue Pine and Chir Pine Forests. Records maintained with the Department show that on an average more than 7,000 ha of Forest are burnt every year from 1994-2020, emitting 84.489 Gg CO_2-e; 14 % of the total emission in the land sector. However, evidence of forest fire was observed in only 61 CP (104 plots) during the NFI.

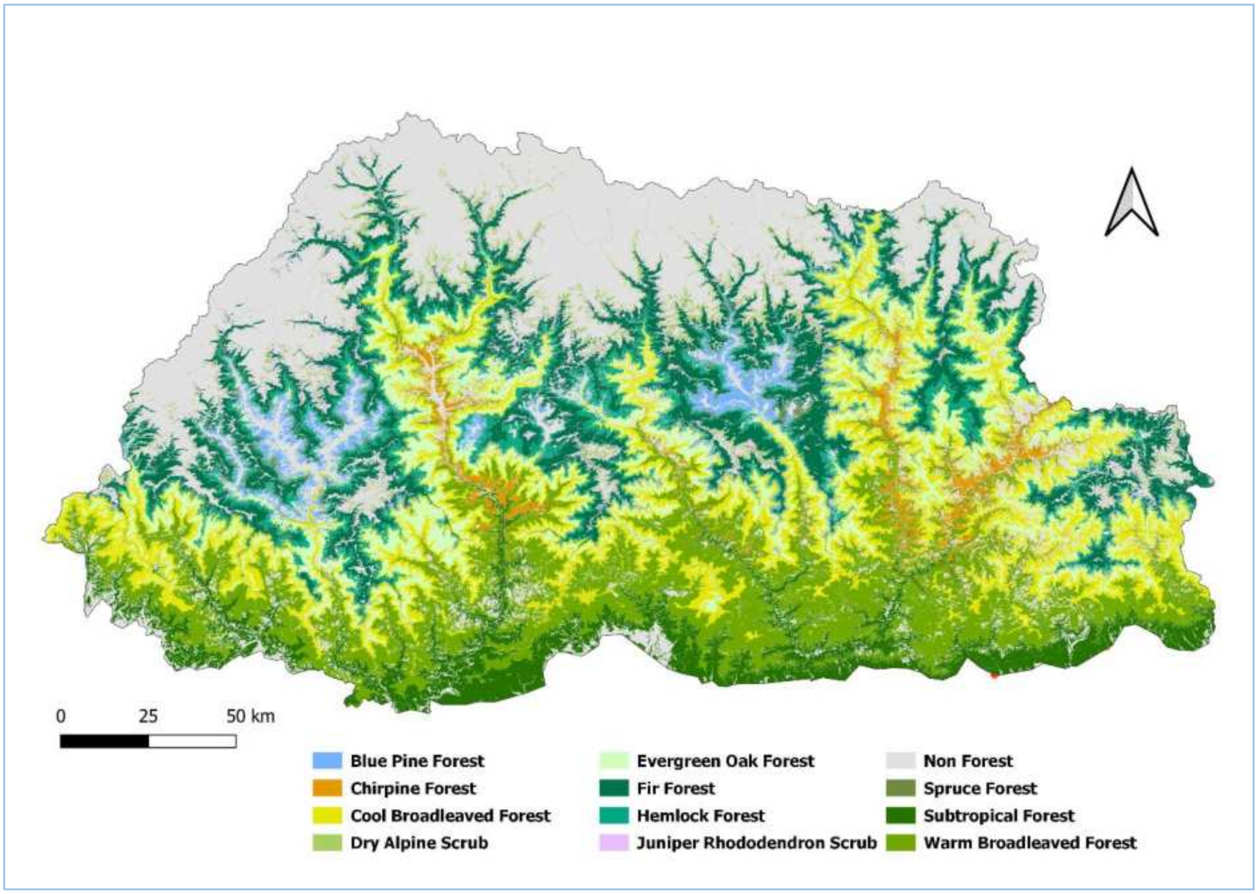


Figure 10.5 Evidence of fire in NFI plots

The majority of the fire are moderate in extent (57 %) and surface in spread (80 %). Underground Fire is uncommon with just 2 % of the total fire evidence detected during the NFI (Figure 10.6).

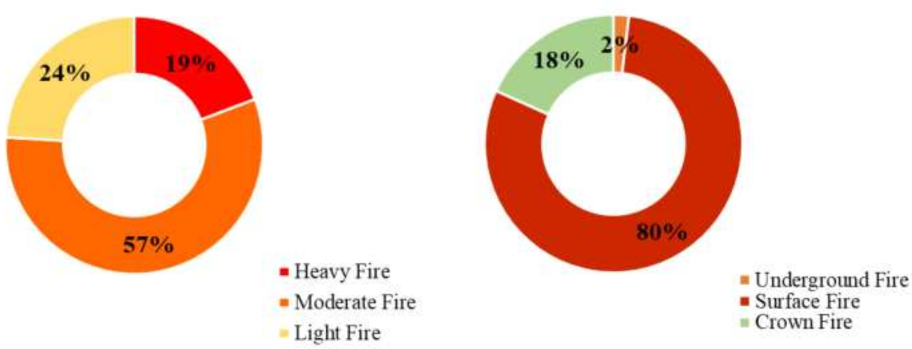


Figure 10.6 Extent and type of Forest Fire

10.6 Garbage

Garbage is another serious issue and like the grazing, it is widespread in the country. NFI recorded evidence of garbage of different types in 227 CP (421 plots). Five categories were defined for data collection; (i) Food wrappers, (ii) Pet bottles, (iii) Construction waste, (iv) Biodegradable waste; and (v) all waste mentioned above.

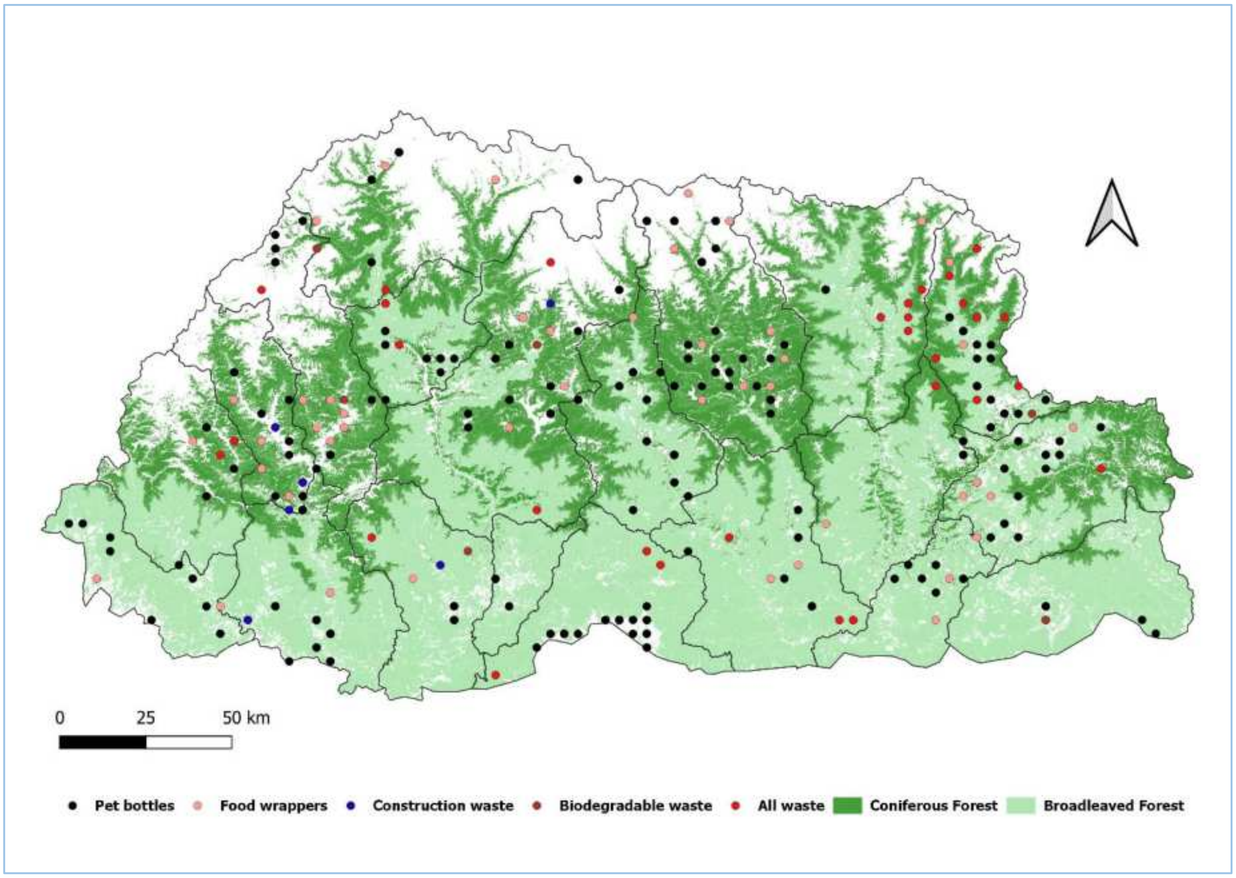


Figure 10.7 Evidence of garbage and waste in NFI plots

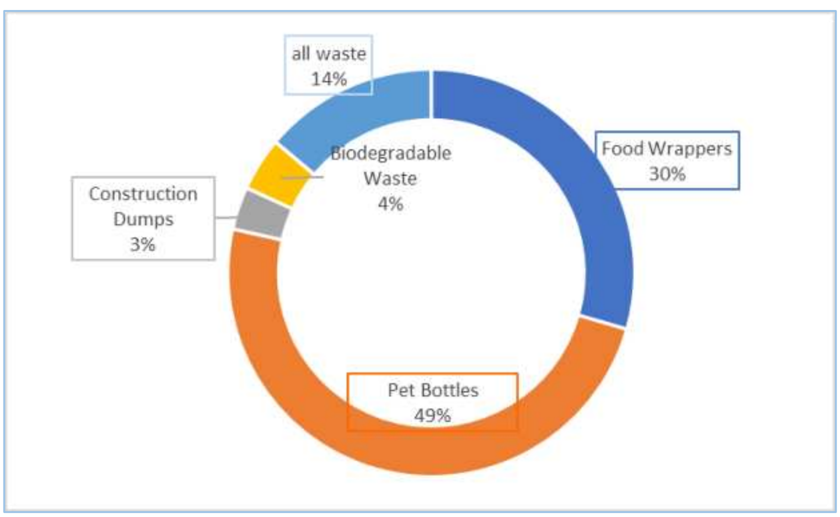


Figure 10.8 Different types of waste recorded

The most common were pet bottles with 49 % of the waste followed by food wrappers (32 %). 12 % of the sites saw evidence of all categories of waste.

NON-WOOD FOREST PRODUCE

11 NON-WOOD FOREST PRODUCE

Bhutan's Forest is home to Non-Wood Forest Produce, which has been utilized by the people for many purposes since time immemorial. About 840 NWFP has been documented in Bhutan[3], however, for the purpose of NFI, the presence or absence data of NWFP was recorded from all plots of 12.62 m radius.

This information shall help the Department in planning for future in-depth resource assessments for key NWFP that can be collected and traded. Further, it also shall guide the identification of scarce and important NWFPs, which need to be studied and preserved. NFI recorded many individual species of medicinal plants of significance and the distribution of these species will be investigated and reported separately later. This chapter emphasizes observation and occurrence records of Bamboo and Canes only.

11.1 Bamboos

Bamboo refers to evergreen perennial flowering plants of the grass family Poaceae and is one of the most important and commonly traded NWFP in Bhutan. 30 species (Stapleton, 1994 as cited in (Moktan et al., 2007)) and 13 genera of bamboo (Noltie, 2000) were recorded in Bhutan. The NFI recorded bamboos in 747 CP and 1600 plot species, and recorded a total of 33 different species of bamboo (including 4 at genus level), which can be grouped broadly into 12 different genera. At the species level, Zhemgang recorded 17 species of total bamboo recorded in 152 plots (34 % of the total plots) while Pemagatshel recorded 13 species and Chhukha, Samdrup Jongkhar, Sarpang, Trongsa and Wangdue Phodrang recorded 12 bamboo species. Gasa and Thimphu recorded only two species of bamboo in the NFI plots.

At the genus level, three different species of *Yushania* were observed and was the most widespread. *Yushania* spp. was observed in 18 Dzongkhags while *Thamnocalamus* spp. and *Arundinaria* spp. were recorded in only three and four Dzongkhags respectively. Figure 11.1 shows the distribution of different types of bamboo in Bhutan.

[3] https://www.fao.org/3/ab598e/AB598E08.htm#TopOfPage

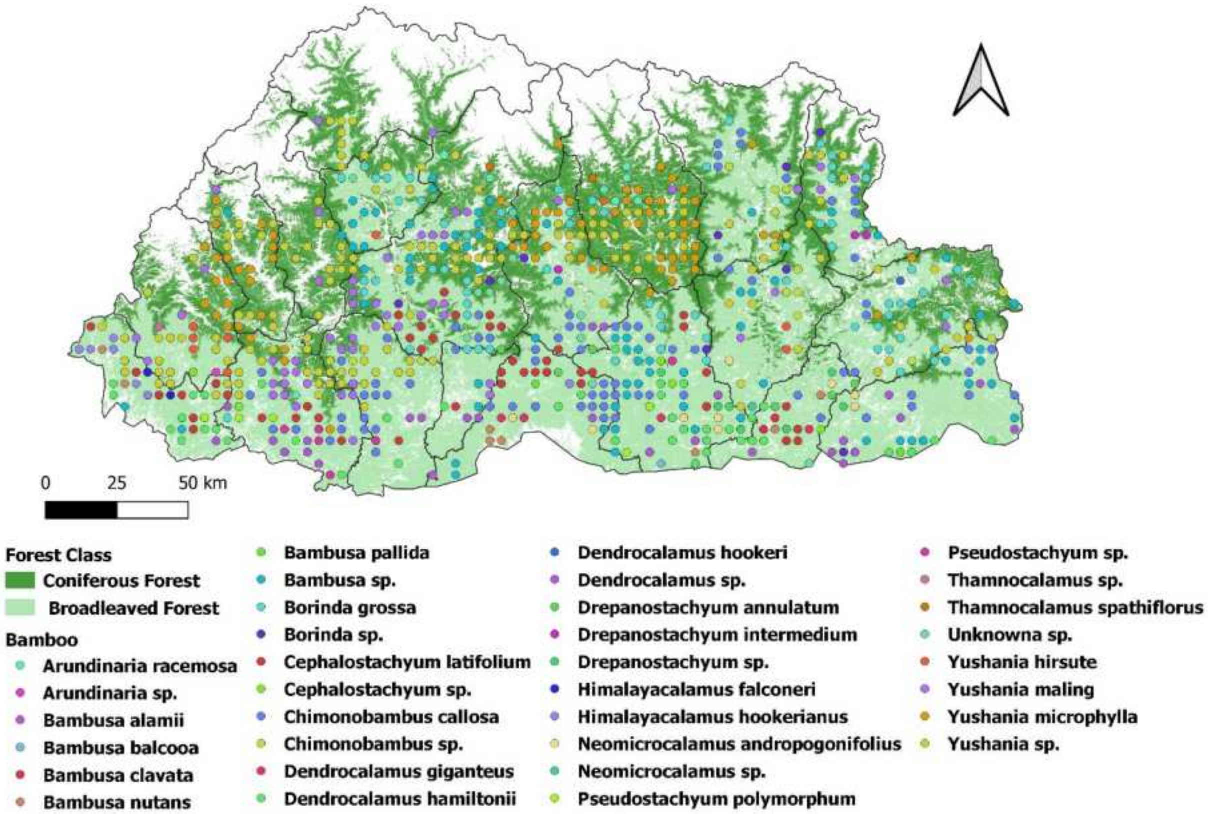


Figure 11.1 Bamboo distribution in Bhutan

11.2 Cane

Canes, like Bamboo are important means of livelihood in parts of the country, though it is, today, used and consumed throughout Bhutan. 10 species of canes were recorded in warmer climatic regions of Bhutan (Moktan et al., 2007; Stapleton et al., 1997). In the NFI, Canes were recorded in 149 CP and 271 plots, below *2,300 m.a.s.l.* Four of *Calamus* spp. and two species of *Plectocomia* spp. were recorded in 14 Dzongkhangs. No canes were observed or recorded in Bumthang, Gasa, Lhuentse and Thimphu in the plots. Zhemgang and Sarpang recorded a higher presence of the cane with observation recorded in 71 and 70 plots respectively, which is about 26 % each of the total cane recorded in the NFI. *Plectocomia himalayana* was the most commonly observed and recorded in 124 plots.

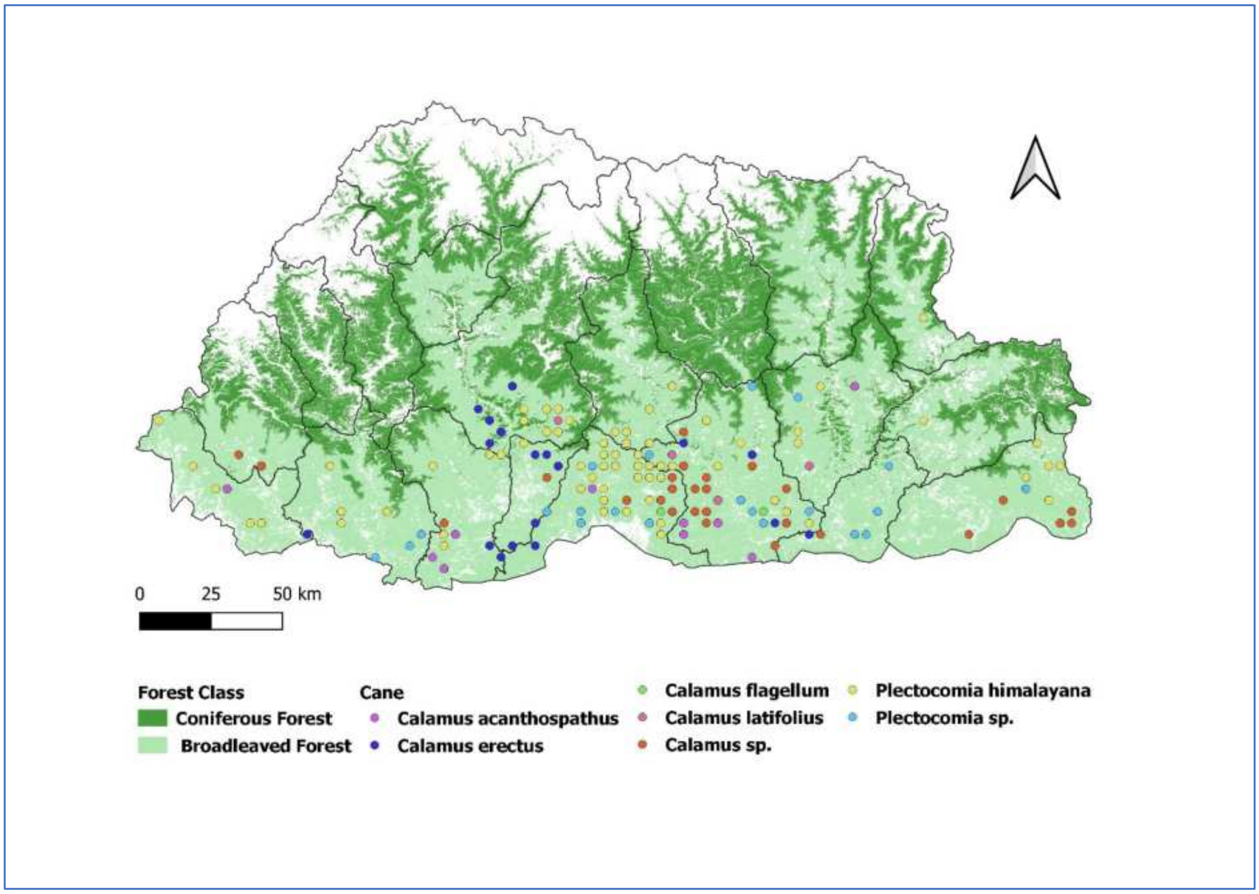


Figure 11.2 Cane distribution in Bhutan

WILDLIFE DISTRIBUTION AND OCCUPANCY

12 WILDLIFE DISTRIBUTION AND OCCUPANCY

12.1 Introduction

Species distribution modelling (SDM) plays a pivotal role in ecological research and conservation planning, providing valuable insights into the spatial distribution and habitat requirement of the wildlife species. By integrating the species occurrence data with environment variables, SDM allows for the identification of critical habitats, the prediction of species range, and the assessment of potential impact from the environmental changes (Guisan et al., 2013). SDM, through the mapping of distribution patterns of species, helps identify area of high species richness, biodiversity hotspots and ecological corridors (Elith et al., 2006). This knowledge aids in the establishment of protected areas, designing the conservation networks, and prioritizing the conservation actions. Furthermore, SDM provides insights about the relationship between environment and species, helping to understand the ecological factors driving the species distribution and their response to environmental changes (Pearson et al., 2004). Such understanding is crucial for predicting species responses to the climate change and informing adaptive management strategies. SDM also plays a vital role in invasive species management. Modelling potential distribution of invasive species assists in predicting their spread and identifying the areas at high risk of invasion (Taucare-Ríos et al., 2016).

One of the widely used SDM is the Maxent. Maxent is a general-purpose machine learning method, well suited for species distribution modelling (Phillips et al., 2006). The model compute a probability distribution based on environmental variables (Pearson et al., 2007), which mean estimated distribution is inferred from environmental condition where species has been observed. One of the key strengths of Maxent is its stability to handle presence-only data, which is often more readily available than absence data. Maxent utilizes the maximum entropy approach (Phillips et al., 2006) to estimate species distribution based solely on available presence record and environmental variables, and has the flexibility of handling both categorical and continuous environmental variable (Phillips et al., 2006). This allows for a comprehensive representation of the species-environment relationship (Elith et al., 2006).

Bhutan's unique geographic features encompass diverse ecosystem, ranging from high-altitude mountain ranges to lush sub-tropical forest. This rich ecological diversity supports a wide array of wildlife species. Therefore, understanding the distribution pattern of these species is vital for prioritizing conservation planning and formulation of effective wildlife management strategies. Beside knowing the spatial distribution for targeting conservation efforts and implementing habitat restoration, the distribution map can also aid in mitigating human-wildlife conflicts, which arise when human activities overlap with wildlife habitats. SDM can also help in informed land-use planning, facilitating a balance between conservation goals and socio-economic needs of local communities in Bhutan.

To provide the crucial insights into the species distribution and to facilitate the identification of critical habitat and assist in human-wildlife conflicts, SDM for ten species were caried using Maxent.

12.2 Presence Data

The presence data for wildlife species were collected during the 2nd NFI. Ten (10) species were selected for species distribution modelling. Presence sample for each of the 10 species is given in the Table 12.1.

Table 12.1 Number of samples for wildlife species

Species	Number of presence sample
Bos gaurus	221
Capricornis thar	248
Elephas maximus	294
Macaca spp.	153
Muntiacus muntjak	902
Naemorhedus goral	277
Pseudois nayaur	320
Sus scrofa	721
Trachypithecus geei	26
Ursus thibetanus	284

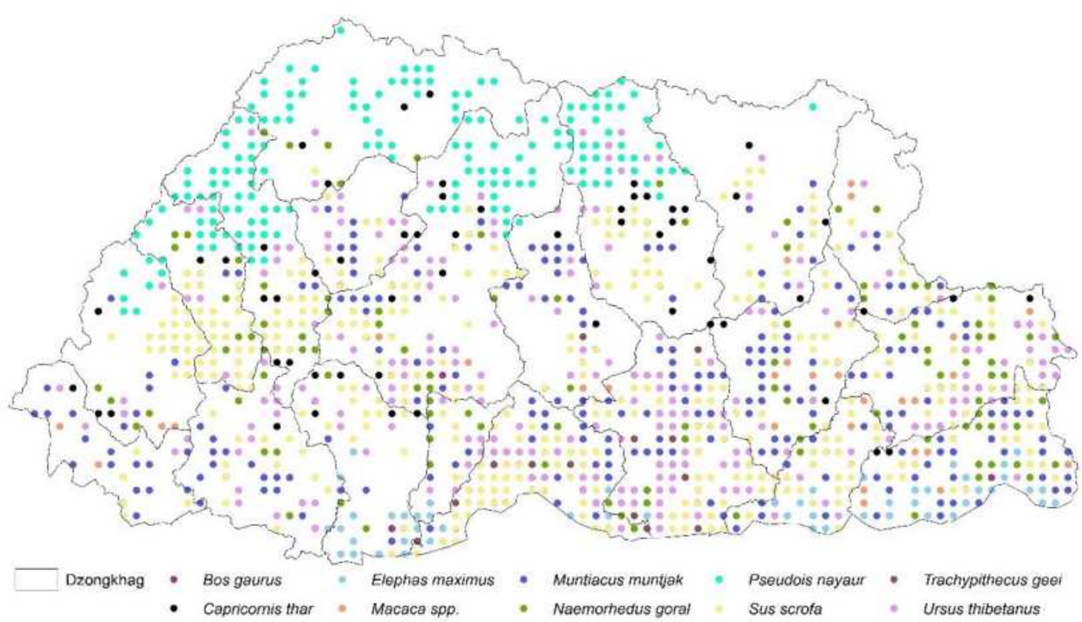


Figure 12.1 Sample collection sites

12.3 Environmental Variables

The environmental data was obtained from the Worldclim (www.worldclim.org). The version 2.1 climatic data which is the historical average of 1970-2000 was downloaded to be used as environmental variable for predicting species distribution. WorldClim is a one of the sources of global climatic data that provides high-resolution gridded climatic datasets. These climatic data is very crucial for understanding species-environment relationships.

The dataset from WorldClim includes 19 climatic variables with a spatial resolution of approximately 1 km^2. Climatic elements considered in the dataset are monthly precipitation and mean, minimum and maximum temperature which has been gathered from variety of sources (Hijmans et al., 2005).

Table 12.2 Climatic variables included in the WorldClim dataset

19 Climatic variables	
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max. Tem3p. - min. temp))
BIO3	Isothermality (BIO2/BIO7)*(100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Maximum Temperature of Warmest Month
BIO6	Minimum Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation of Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

12.4 Distribution Modelling

Maxent model was trained using the presence data. Around 80 percent of presence data was used for training the model and 20 percent was used for testing. Feature types such as linear, quadratic, and hinge features were included to capture the relationships between the target species occurrence and selected environmental variables. Default settings of Maxent, including logistic response curve have been used. Default parameters of Maxent were set as: regularization multiplier = 1; maximum number of background points 10000 and maximum iteration 500. The replicates were set to 25 and cross validate was selected for replicated run type.

The model's prediction accuracy is quantified in terms of AUC (area under receiver operating characteristic (ROC) curve). The red line (training line) represents model's fit to the training data, while blue line (testing line) represents the model's fit to the testing data, which is the true test of the model's prediction power. Further towards the top left of the graphs the blue line is, better the model is, at predicting presence contained in the test sample data. The value for AUC ranges from 0 to 1. Values close to 0.5 indicates a fit not better than that expected by random while values close to 1 indicate more accuracy and a perfect fit.

Maxent also gives various methods to know the importance of environmental variable in predicting the species distribution. Percent contribution, permutation importance and jackknife were utilized to assess the significance and contribution of individual environmental variables. Percent contribution quantifies the proportion of the model's output variance that can be attributed to each predictor variable. A higher percent contribution indicates a greater influence of that variable in shaping the species habitat suitability and distribution patterns. Permutation importance on other hand measures the importance of each environmental variable by assessing its impact on the model's predictive accuracy. Variables with higher permutation importance values are considered more influential in the model and have a greater impact on the species habitat suitability or distribution pattern. The *Jacknife* resampling techniques provides a measure of the sensitivity of the model to the inclusion or exclusion of each variable. It helps to identify the variables that have the greatest influence on the model's performance and determine their relative importance in accurately predicting the habitat suitability and distribution pattern

12.5 Results

12.5.1 Gaur (*Bos gaurus*)

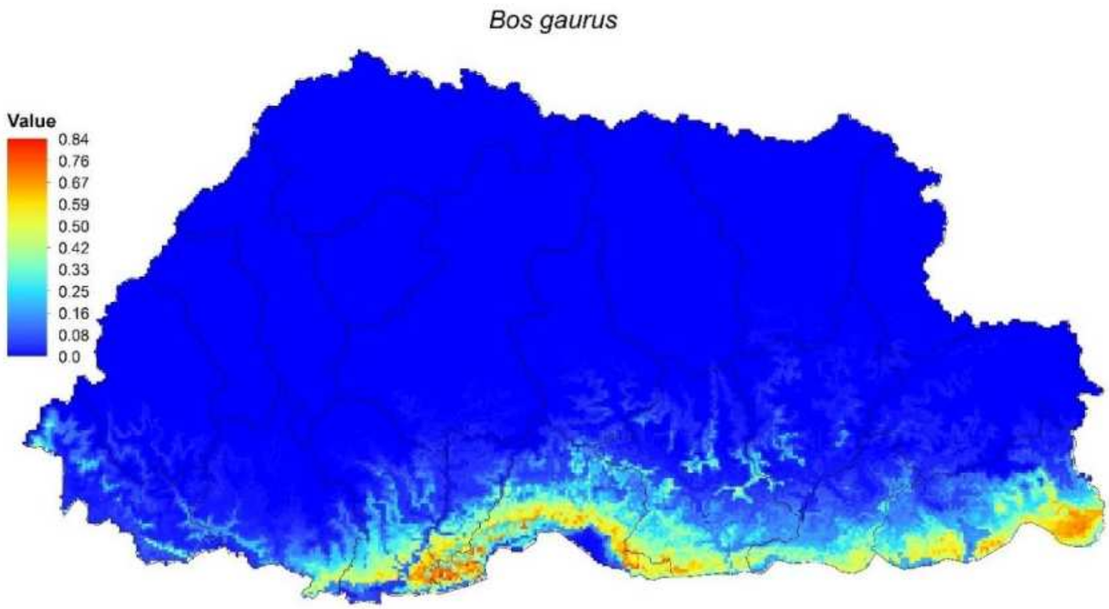
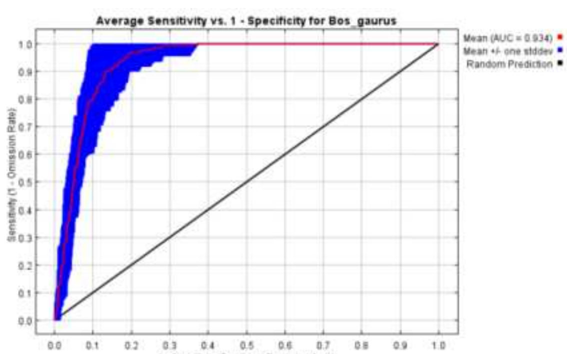
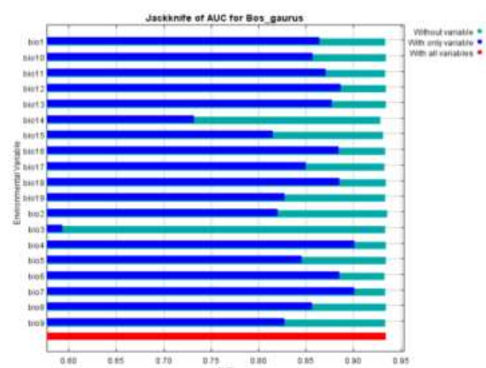


Figure 12.2 Occupancy of Gaur (Bos gaurus)

Gaur (*Bos gaurus*) is largely found in the southern part of Bhutan, particularly in Sarpang and Samdrup Jongkhar. The gaur habitat is found significantly in Phibsoo Wildlife Sanctuary, Jomotshangkha Wildlife Sanctuary, and Royal Manas National Park. Guar habits seems to be overlapping with elephant habitat in Bhutan.





12.5.2 Himalayan Serow (*Capricornis thar*)

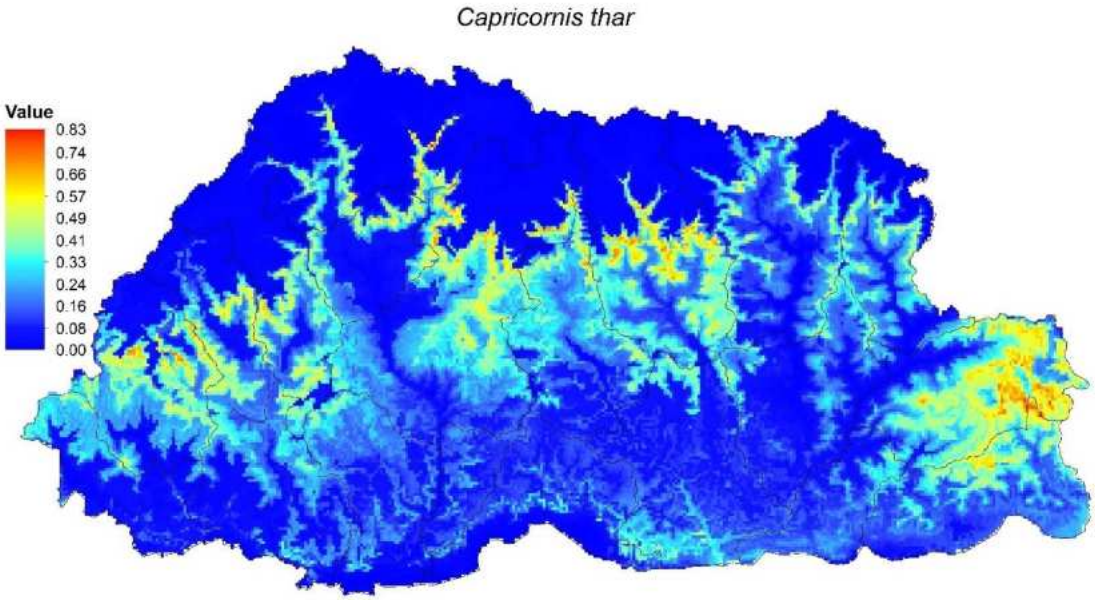
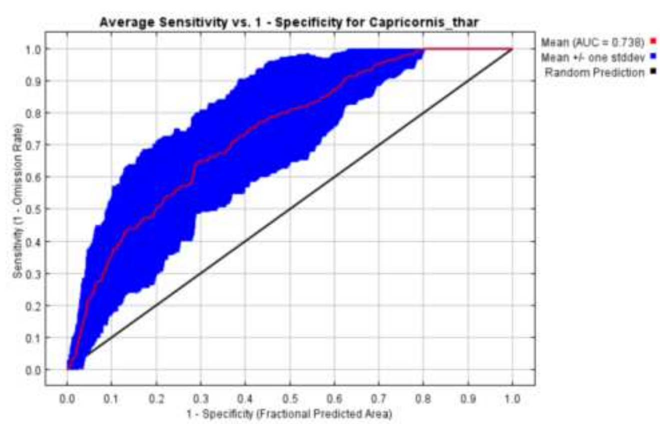
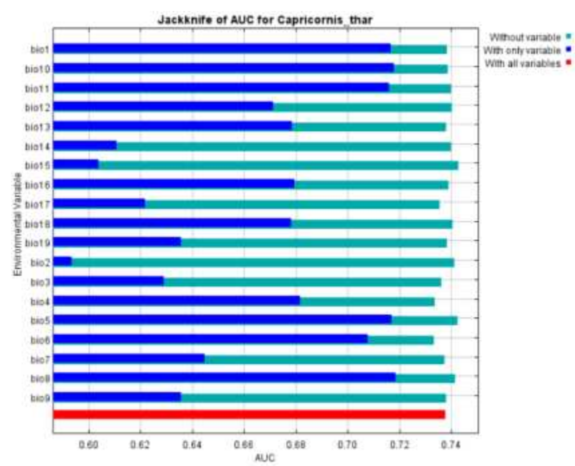


Figure 12.31. Himalayan Serow (Capricornis thar)





Himalayan Serow (*Capricornis thar*) typically inhibits steep, rocky and forested area at high altitudes. The distribution patterns reveal that potential habitat and its distribution is mostly concentrated in Trashigang, Bumthang, Wangdue Phodrang, Haa, Thimphu and Paro. Sakteng Wildlife Sanctuary, Wangchuck Centennial National Park, Jigme Dorji National Park, Biological Corridor (BC) 8 & 6 are some of the protected area (PA) networks that serves as habit for Himalayan Serow.

12.5.3 Asian Elephant (*Elephas maximus*)

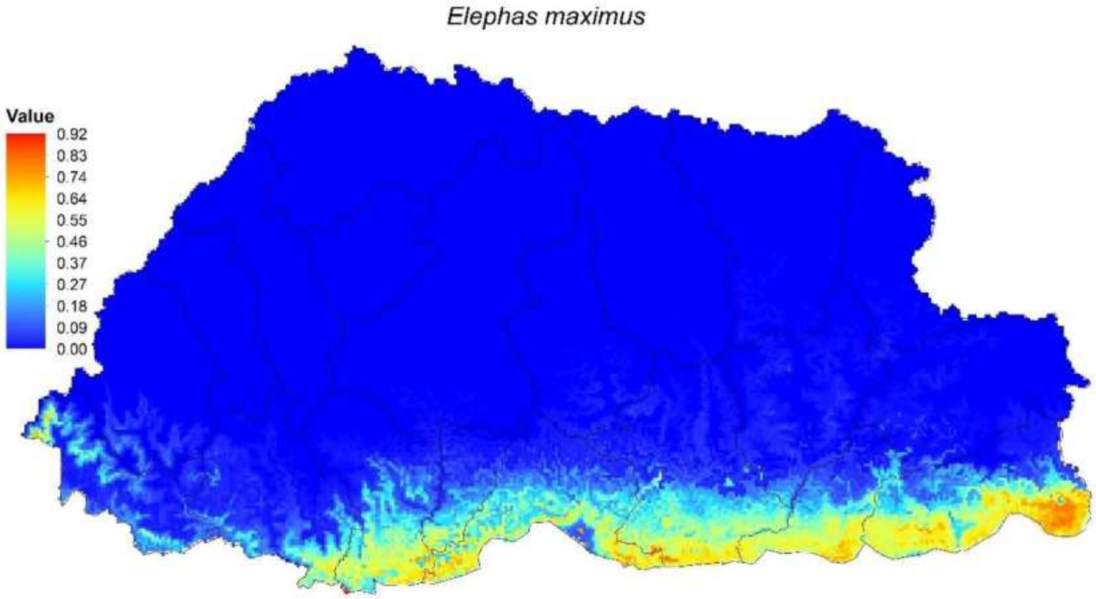
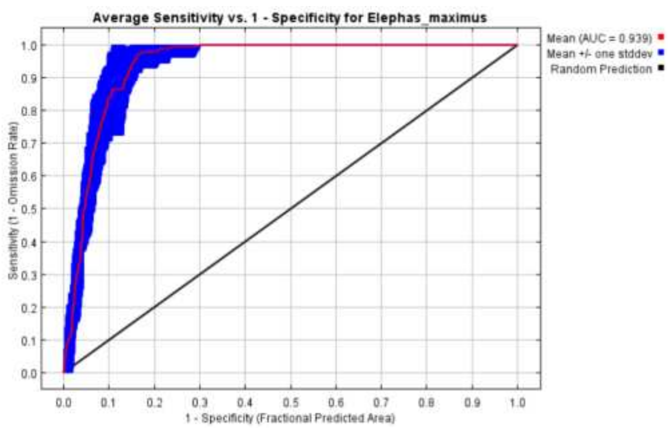
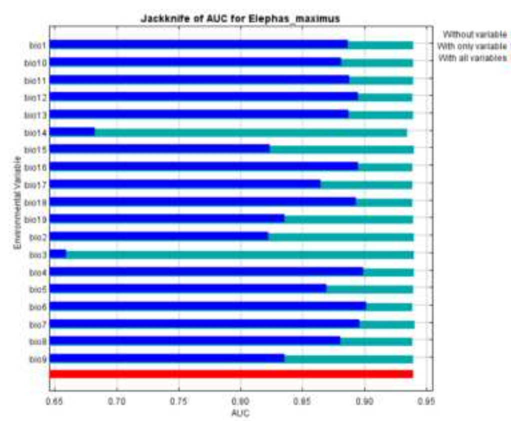


Figure 12.42. Asian Elephant (Elephas maximus)





Asian Elephant (*Eliphas maximus*) primarily inhabit the southern foothills in the southern part of the country. They are known to occur in Samtse, Chhukha, Dagana, Sarpang, Zhemgang, Pemagatshel, and Samdrup Jongkhar. These regions provide suitable habitats with a mix of grasslands, forests, and wetlands that are crucial for the elephants' survival. Phibsoo wildlife Sanctuary, Royal Manas National Park, Jomotsangkha Wildlife Sanctuary and BC 5 within the PA network which are seen as the habit for elephants.

12.5.4 Monkey (*Macaca* spp.)

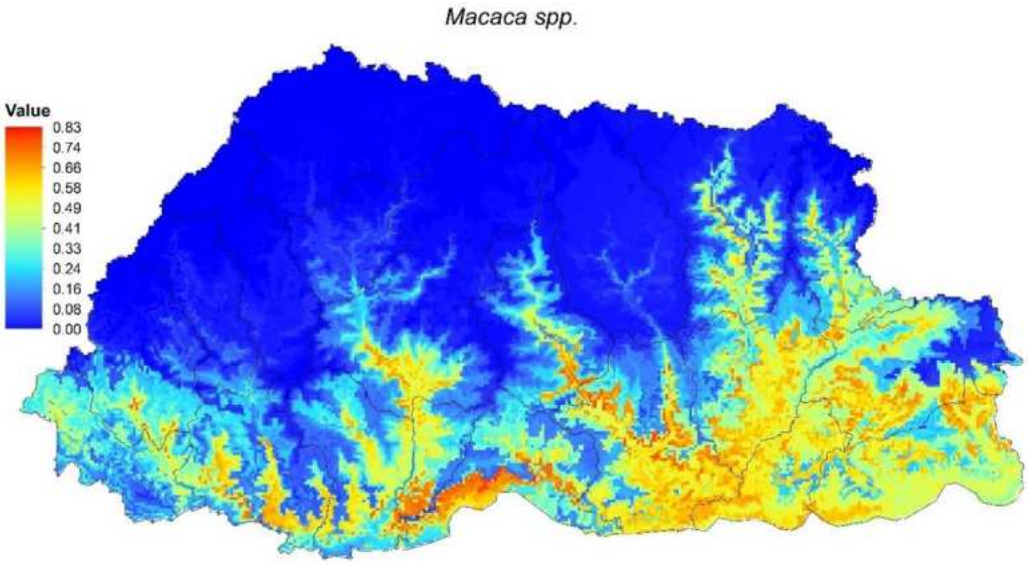
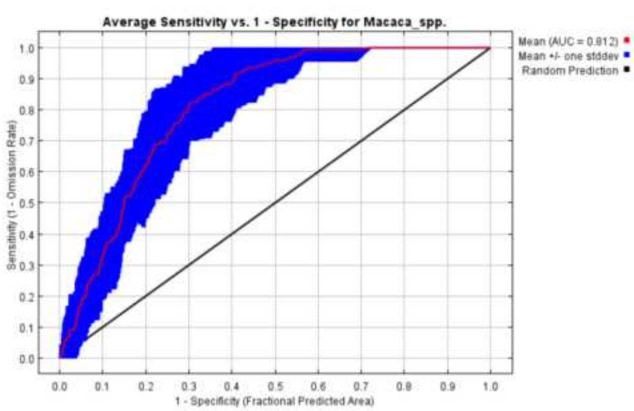
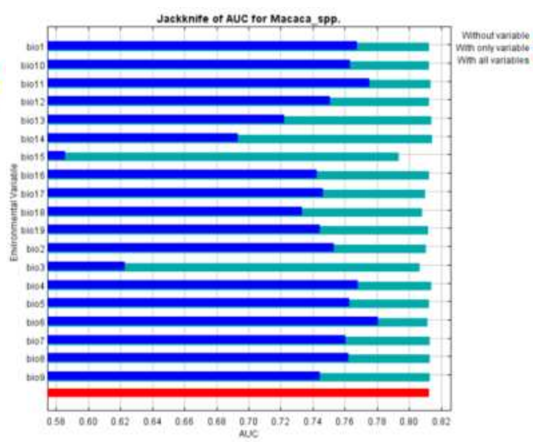


Figure 12.5 .   Monkey (Macaca spp.)





Spatial distribution of both Assamese macaque and Rhesus macaque was caried out together. The model predicted the suitable habit for monkey throughout Bhutan but mostly concentrated in the sub-tropical and temperate regions. The predicted map depicts that habitat is more suitable in Dzongkhags like Trashigang, Mongar, Samdrup Jongkhar, Zhemgang, Pemagatshel, Sarpang, Tsirang, Samtse, Chukha and Dagana. Lower region of Wangdue Phodrang and Trongsa are seen to be potential habitat for monkey.

12.5.5 Barking Deer (*Muntiacus muntjak*)

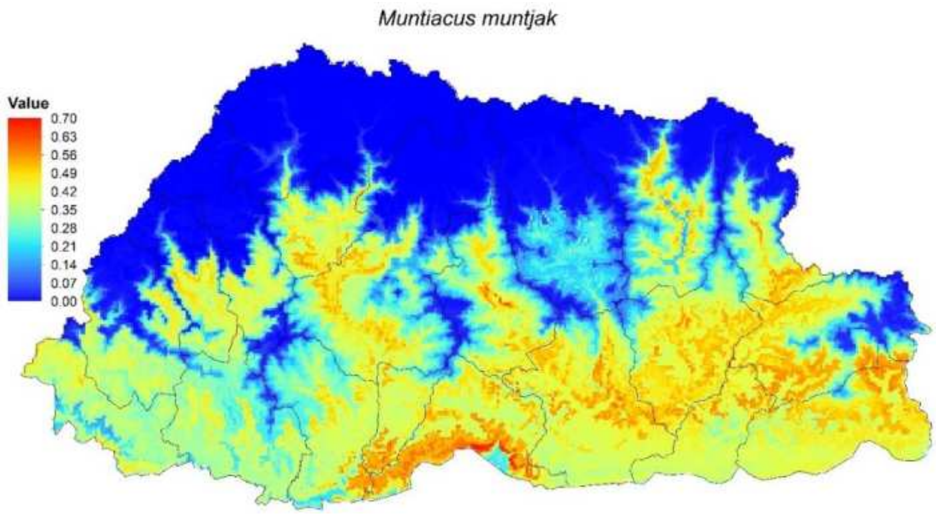
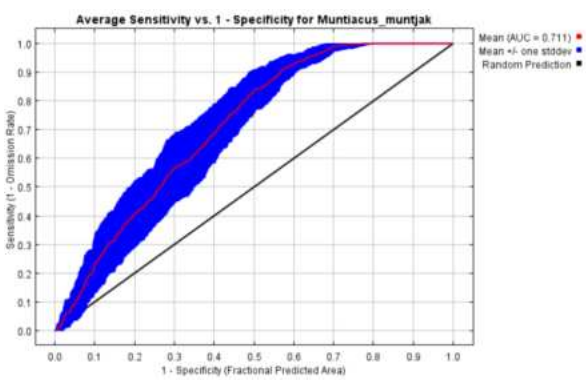
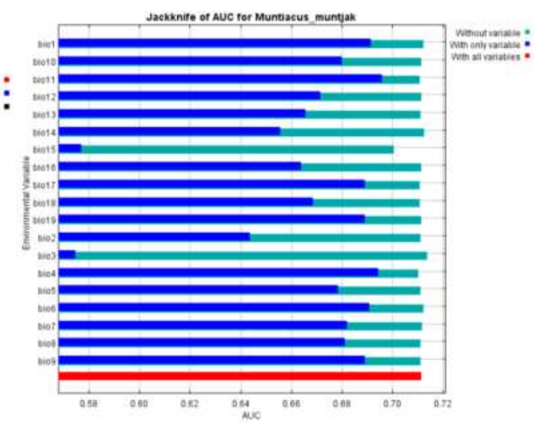


Figure 12.6 Barking Deer (Muntiacus muntjak)





The model predicts that *Muntiacus Muntjak* popularly known as barking deer can be found throughout Bhutan. Model also predicted that habitat for braking deer appear to occupy diverse ecosystem ranging from subtropical to temperate region in the country. However, their preference for habitat appears to be more in the broad-leaved forests where climatic condition is warm.

12.5.6 Himalayan Goral (*Naemorhedus goral*)

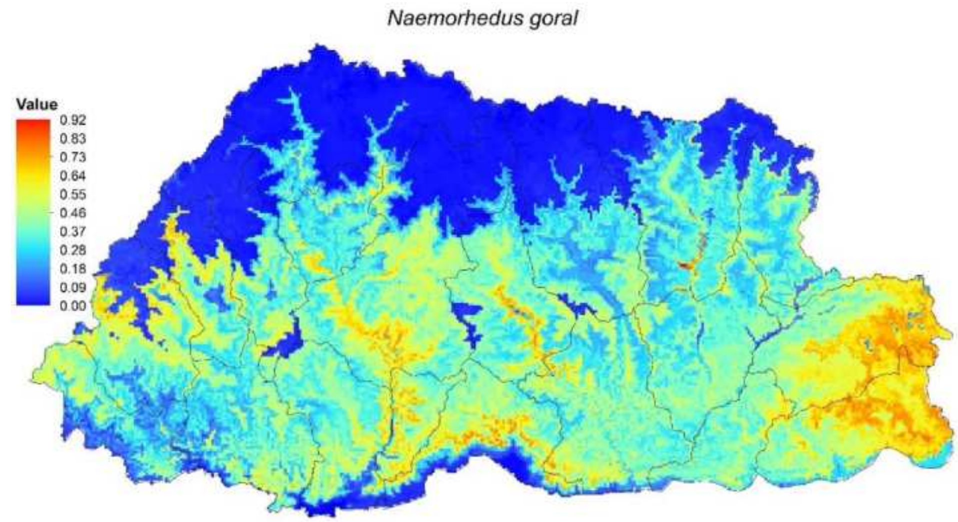
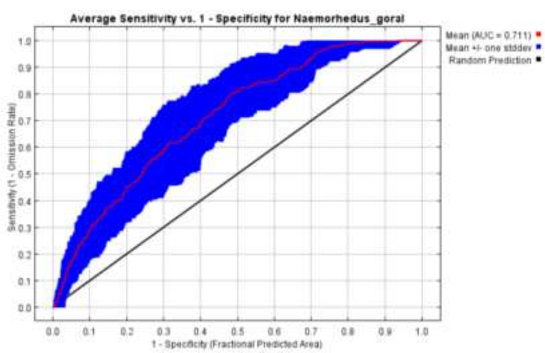
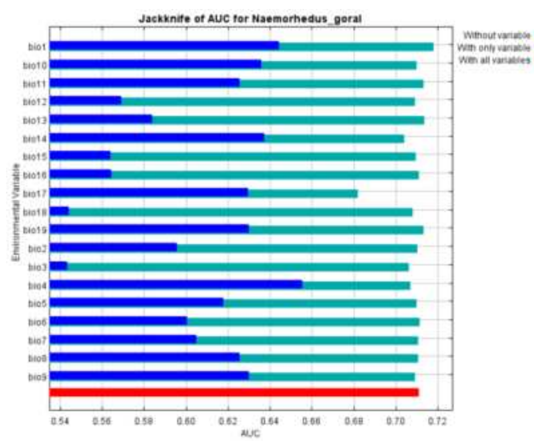


Figure 12.7 Himalayan Goral (Naemorhedus goral)





Himalayan goral (*Naemorhedus goral*) is a species of small ungulate, or goat-antelope, that inhabits the high-altitude regions of the eastern Himalayas, including Bhutan. The model predicts the presence of the Himalayan goral throughout Bhutan. However, its potential habitat is mostly located in high-altitude region of Trashigang and Samdrup Jongkhar. Other high-altitude area in Samtse, Haa, Thimphu, Wangdue Phodrang, Trongsa, Tsirang and Sarpang also seems to be potential habitat for Himalayan goral. Sakteng Wildlife Sanctuary, BC 8 and Jomotshangkha Wildlife Sanctuary appears to be a habitat for Himalayan goral.

12.5.7 Blue sheep (*Pseudois nayaur*)

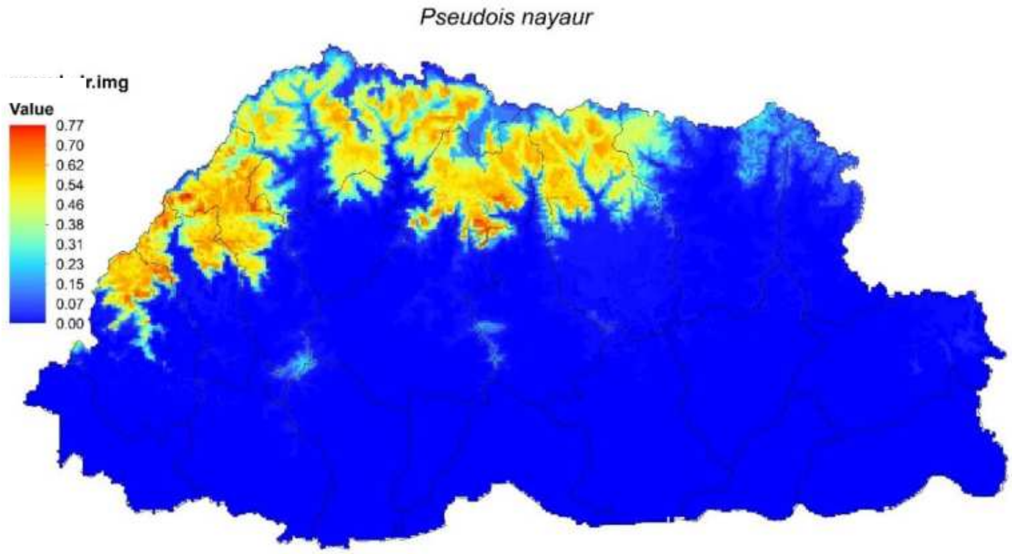
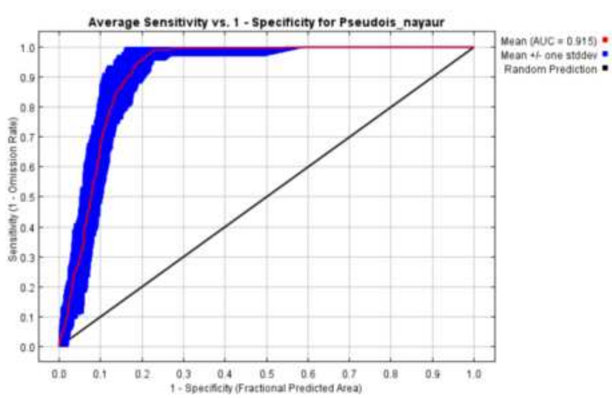
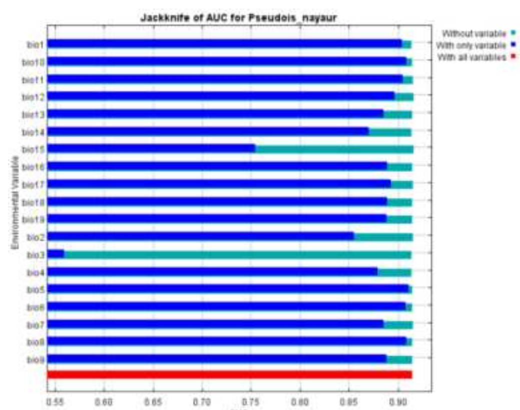


Figure 12.8 Blue sheep (Pseudois nayaur)





Blue sheep (*Pseudois nayaur)* is a species of sheep found in the high-altitude regions of the Himalayas, including Bhutan. In Bhutan, they are primarily found in the mountainous regions of northern parts of the country. They inhibit alpine meadows, steep slopes, rocky cliffs, and shrublands at higher elevation. Northen most part of Bumthang, Wangdue Phodrang, Gasa, Thimphu, Paro, and Haa are some Dzongkhags that appears have potential distribution of blue sheep. Jigme Dorji National Park and Wangchuck Centennial National Park appears to serve as potential habitat for this species.

12.5.8 Wild boar (*Sus scrofa*)

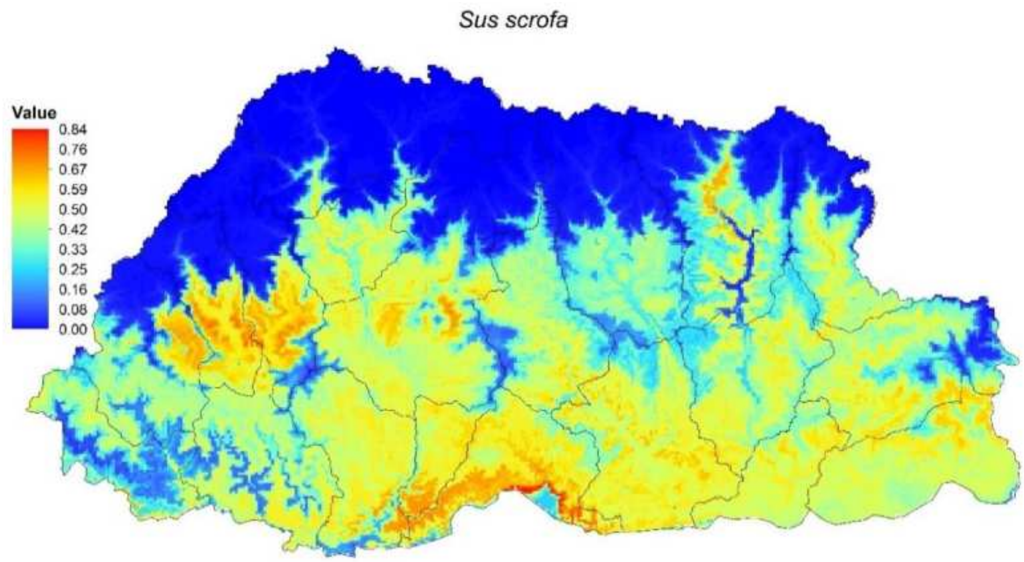
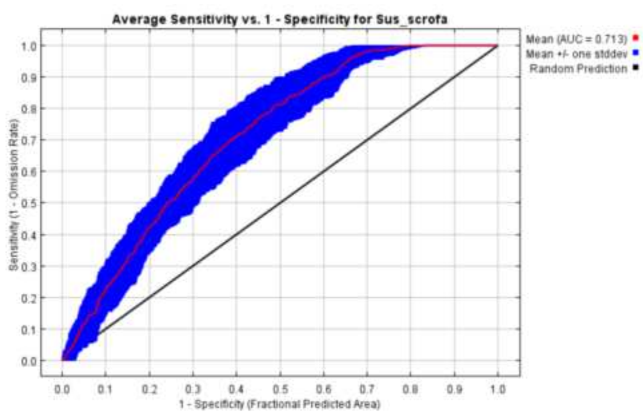
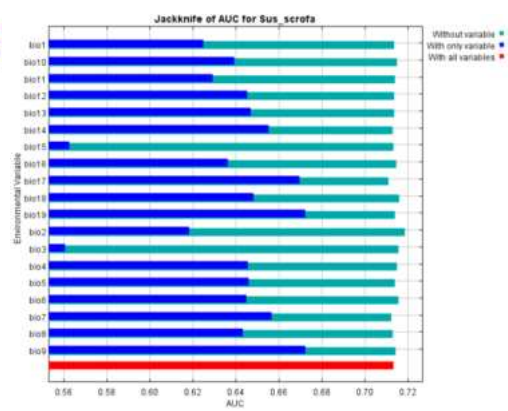


Figure 12.9 Wild boar (Sus scrofa)





Wild boar is widespread and adaptable species found in various habitats, occupying diverse ecosystems ranging from lowland forests to higher elevations. Wild boar appears to be distributed though out the country. Wild boars are opportunistic feeders that cause significant crop damage in Bhutan. Their feeding habit can lead to economic losses for farmers and impact food security in the affected area. Additionally, wild boars have a rapid reproductive and proliferate in short period of time.

12.5.9 Golden langur (*Trachypithecus geei*)

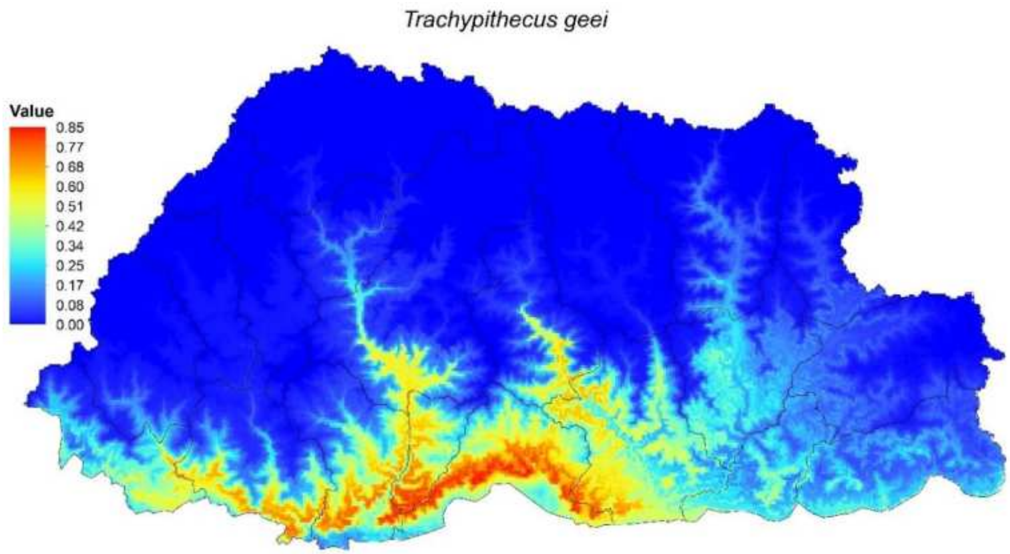
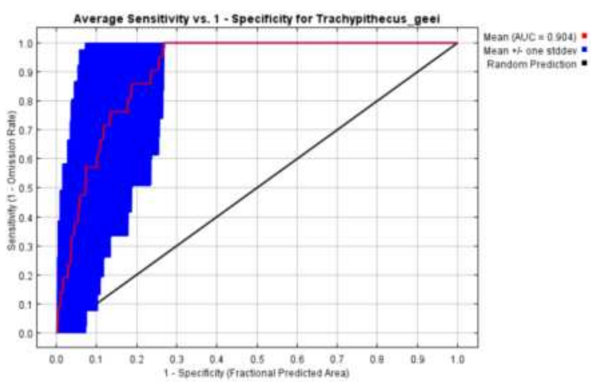
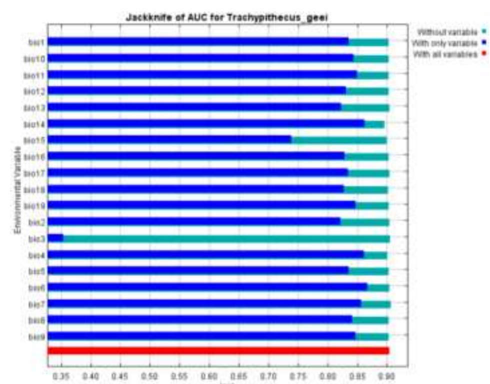


Figure 12.10 Golden langur (Trachypithecus geei)





Golden langur (*Trachypithecus geei)* is as an endangered species listed under the IUCN Red List of Threatened Species. In Bhutan, this species is limited to specific areas, mainly in the central-southern part of the country. According to the model, their spatial distribution is mostly concentrated in Sarpang, lower region of Zhemgang, Tsirang and Dagana. Royal Manas National park, Phibsoo wildlife sanctuary and BC 3 appears to be the critical habitat for the golden langur.

12.5.10 Asiatic Black Beer (*Ursus thibetanus*)

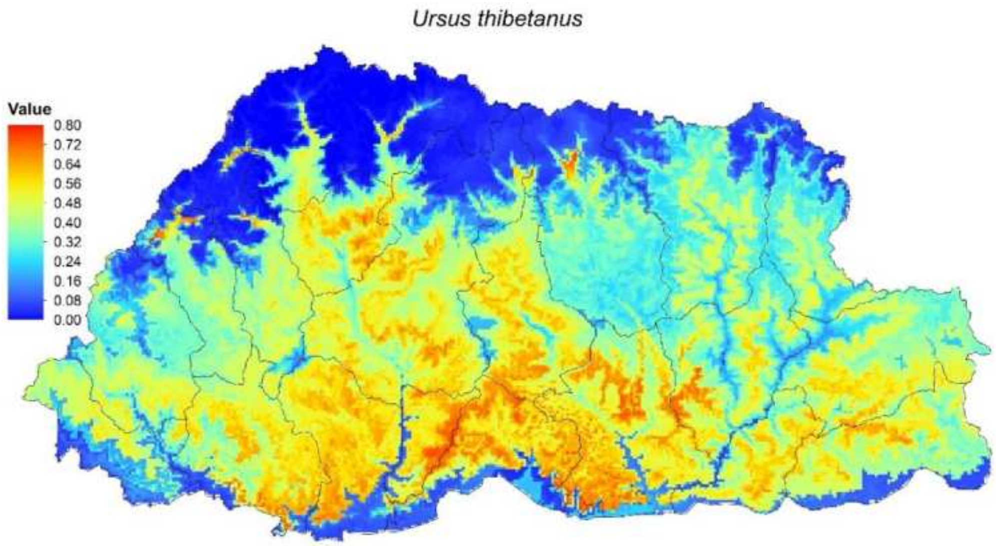
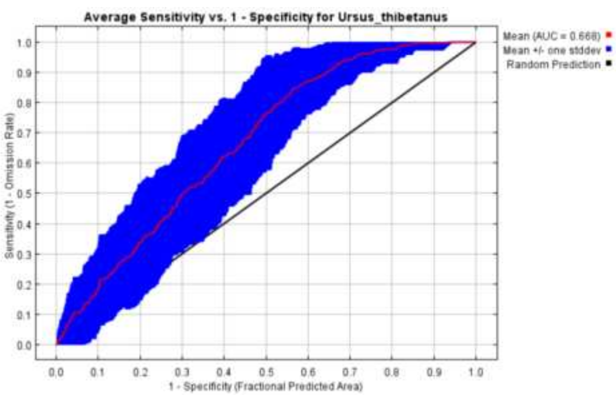
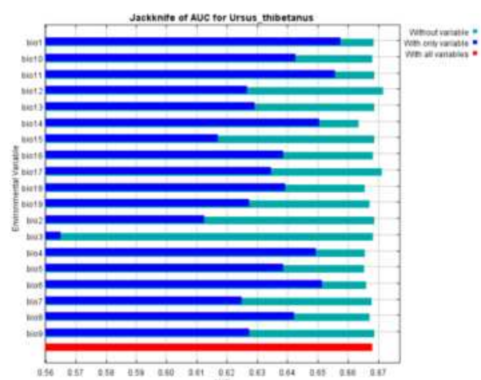


Figure 12.11 Asiatic Black Beer (Ursus thibetanus)





Asiatic black beer also appears to be distributed throughout the country. They prefer the habitat with thick vegetation cover. The model shows that black beer occupies diverse ecosystem ranging from sub-tropical forest in the south to alpine region in the north.

13 WAY FORWARD

National Forest Inventory provides comprehensive information on the current state of forest resources of Bhutan which is estimated based on the data collected from the 1,969 Cluster Plot. 455 Cluster Plots were inaccessible. Considering the sampling intensity of 0.009% of the NFI, attributes of each NFI cluster plot represent approximately 1,600 ha. Therefore, the estimates reported in this report are very useful at the National and Dzongkhag levels, while they may be applied with caution in smaller reporting units such as *Gewog* or *Chiwog*. Some of the finding and recommendation from the 2nd NFI are:

General

- Sampling intensity for NFI is quite low and therefore, requires intensification of plots to better understand the state of our forest resources and health, and plan for resource use effectively.
- 455 NFI cluster plots were inaccessible and are considered non-response. This non-response plot is not included in the estimation of forest attributes, which may have resulted in over or underestimation. Therefore, all efforts should be made to access these plots or use the technologies to impute the values for the non-response plots.
- NFI also recorded a high density of the smaller size trees with a declining number of the larger size trees. Proper stand management is recommended for the DBH growth in the Forests.
- NFI plots are 4 km x 4 km aerial distance apart and adequate time may be provided to crews for enumeration.
- NFI primarily focuses on Forest land. The inclusion of other land categories and detailed assessment may be needed for complete carbon accounting in SRF land.

Forest Area Estimation

- Canopy density is measured using 25 points against the general requirement of the 100 points reading in the GRS crown densitometer. Future inventories should consider measurement of 100 or more points for canopy cover estimates.

Plant Identification and Land Stratification

- A very high number of unknown species were recorded in the NFI. Given the terrain and the location of the CP, the crew should be adequately trained in plant taxonomy and botany for the correct identification of the plants.
- There is no clear distinction between Forest Types in terms of species composition and there is a high possibility of mis-classification of Forest Types. The current Forest Type classification may be reviewed.

Growth and Increment

- Measuring the tree height was very challenging even with sophisticated equipment. And it is recommended to develop a Height-Diameter model for major species or species groupings.
- Basal area increment and volume increment are based on the tree ring data and estimated from only about 4,100 cores for this report. A total of 8,500 cores samples were collected from the forest but only about 4,100 cores could be measured. Future NFI should explore the re-measurement of the plots to compute the increment.
- The Volume equation used for estimation was developed during the PIS (1974-1981) and some of the volume equations predict negative volume for smaller DBH trees. Therefore, the volume equation needs to be updated. Further, there are no growth models for our Forest ecosystem.
- While the NFI is a permanent sample plot, it is difficult to directly compare the tree to tree and plot to plot data for 1st NFI and 2nd NFI as the some of the plot centers of the 1st NFI could not be located for re-measurement. And, for plots that were relocated, the crews could match the tree-to-tree information. Therefore, future inventories should attempt relocation of the plot centre and re-measurement of each plot and tree, which are tagged with uniquely numbered tree tags.

Understorey Above Ground Biomass, litter and soil samples

- Understorey carbon samples were collected from only about 20 % of the total plots. Future inventories may/should consider collecting samples from all plots or stratify the sample collection by land categories and Forest types.
- Review the sampling design for soil and litter samples and test collection of samples from all plots or stratification of the sample locations.

Disturbance

- The NFI results provided an indication of the presence of Mistletoe infestation in the Broadleaved Forest. This was consistent with the findings from the 1st NFI. Detail assessment of the extent damage caused by the Mistletoes is recommended.
- Dieback in the forest is widespread. The extent of the damage requires a detailed assessment.
- Grazing was prevalent both in Coniferous and Broadleaved Forests.

NFI Data management

- Currently, NFI is using the Open Foris tools of 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 different inventory cycles. Therefore, it is important to develop an NFI database with basic analytical features.

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

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15 APPENDICES

Chapter 4 Stem Density

1. Total tree count by Dzongkhag

Dzongkhag	Tree count	MoE (%)	Lower Limit	Upper Limit
Bumthang	61,060,979	13	52,975,765	69,146,194
Chhukha	49,367,199	13	43,090,870	55,643,529
Dagana	69,037,242	11	61,719,815	76,354,669
Gasa	20,106,768	22	15,603,891	24,609,645
Haa	50,069,946	16	42,085,829	58,054,063
Lhuentse	56,249,304	14	48,149,041	64,349,568
Mongar	60,071,892	14	51,931,222	68,212,563
Paro	27,095,315	18	22,099,954	32,090,677
Pemagatshel	43,458,562	16	36,675,066	50,242,058
Punakha	31,885,076	16	26,775,954	36,994,199
Samdrup Jongkhar	53,580,132	11	47,776,858	59,383,405
Samtse	26,289,705	14	22,576,375	30,003,034
Sarpang	51,533,446	11	45,860,793	57,206,099
Thimphu	33,875,803	17	28,076,023	39,675,584
Trashigang	67,918,186	16	57,304,193	78,532,179
Trashi Yangtse	33,380,764	17	27,758,664	39,002,863
Trongsa	60,515,434	13	52,539,483	68,491,385
Tsirang	20,448,099	21	16,149,425	24,746,773
Wangdue Phodrang	101,655,746	11	90,528,979	112,782,513
Zhemgang	85,730,493	9	78,420,814	93,040,173

2. Total sapling count by Dzongkhag

Dzongkhag	Sapling Count	MoE (%)	Lower Limit	Upper Limit
Bumthang	21,022,508	21	16,629,972	25,415,045
Chhukha	34,783,286	19	28,251,815	41,314,756
Dagana	24,629,421	19	20,064,573	29,194,268
Gasa	36,099,136	58	15,307,634	56,890,637
Haa	27,925,508	26	20,636,634	35,214,382
Lhuentse	29,490,813	26	21,688,997	37,292,630
Mongar	26,493,913	21	20,944,928	32,042,898
Paro	19,679,441	30	13,758,794	25,600,088
Pemagatshel	24,891,223	32	16,941,875	32,840,572
Punakha	15,277,753	34	10,049,562	20,505,944
Samdrup Jongkhar	33,056,919	15	28,065,015	38,048,823

Samtse	8,764,939	24	6,672,584	10,857,295
Sarpang	22,821,882	14	19,518,915	26,124,849
Thimphu	5,029,250	29	3,563,500	6,495,000
Trashigang	40,193,559	18	32,868,124	47,518,993
Trashi Yangtse	19,889,681	34	13,143,444	26,635,918
Trongsa	35,442,984	28	25,650,416	45,235,551
Tsirang	10,852,730	29	7,697,039	14,008,421
Wangdue Phodrang	53,046,086	21	41,893,317	64,198,854
Zhemgang	39,267,184	13	34,258,334	44,276,033

3. Total tree count by Forest Type

Forest Type	Tree Count	MoE (%)	Lower Limit	Upper Limit
Subtropical Forest	110,494,525	6	103,596,203	117,392,846
Chirpine Forest	19,910,043	19	16,171,098	23,648,987
Warm Broadleaved Forest	250,950,030	6	236,758,012	265,142,048
Evergreen Oak Forests	16,937,078	19	13,778,204	20,095,952
Cool Broadleaved Forest	314,260,333	6	296,863,377	331,67,289
Blue Pine Forest	44,116,829	15	37,372,662	50,860,995
Spruce Forest	16,953,786	16	14,198,576	19,708,995
Hemlock Forest	52,978,309	14	45,593,966	60,362,652
Fir Forest	174,027,288	7	162,136,438	185,918,137
Juniper Rhododendron Forest	18,749,058	22	14,586,428	22,911,688

4. Total sapling count by Forest Type

Forest Type	Sapling count (No.)	MoE (%)	Lower Limit	Upper Limit
Subtropical Forest	57,178,636	8	52,393,920	61,963,352
Chir Pine Forest	10,057,439	30	7,024,266	13,090,613
Warm Broadleaved Forest	118,199,074	10	106,106,143	130,292,005
Evergreen Oak Forests	14,233,530	38	8,852,230	19,614,829
Cool Broadleaved Forest	137,134,754	10	123,160,693	151,108,815
Blue Pine Forest	21,335,059	27	15,535,784	27,134,334
Spruce Forest	7,543,434	41	4,415,284	10,671,583
Hemlock Forest	26,507,254	28	19,040,084	33,974,424
Fir Forest	117,266,375	17	97,709,301	136,823,449
Juniper Rhododendron Forest	18,892,567	57	8,158,169	29,626,966

5. Total tree count by Elevation

Elevation Range	Tree Count	MoE (%)	Lower Limit	Upper Limit
<1000	109,251,256	7	101,067,138	117,435,373
1000-2000	280,197,289	7	261,832,258	298,562,320
2000-3000	357,237,185	6	335,469,714	379,004,656
3000-4000	245,435,584	7	228,076,778	262,794,391
>=4000	18,429,498	32	12,543,927	24,315,069

6. Total sapling count by Elevation

Elevation	Sapling count (No.)	MoE (%)	Lower Limit	Upper Limit
<1000	56,615,203	10	50,997,021	62,233,386
1000-2000	134,209,005	10	120,247,635	148,170,375
2000-3000	162,009,516	10	145,117,515	178,901,516
3000-4000	155,944,762	15	131,858,407	180,031,116
>=4000	19,893,524	48	10,421,542	29,365,505

7. Total tree count by DBH Class

DBH Class (cm)	Tree Count	MoE (%)	Lower limit	Upper limit
10-20	510,532,853	4	488,417,356	532,648,351
20-30	213,406,053	4	204,735,588	222,076,517
30-40	112,361,606	4	107,772,303	116,950,910
40-50	62,729,241	5	59,801,926	65,656,556
50-60	38,571,895	6	36,410,533	40,733,257
60-70	24,636,500	6	23,067,645	26,205,355
70-80	15,891,940	7	14,725,786	17,058,095
80-90	11,590,963	8	10,606,884	12,575,042
90-100	6,942,028	10	6,231,688	7,652,368
>=100	11,454,062	10	10,358,892	12,549,231

8. Total tree count by Height class

Height Class (m)	Tree count	MoE (%)	Lower limit	Upper limit
<5	29,781,701	11	26,430,225	33,133,177
5-10	340,826,784	5	324,020,666	357,632,902
10-15	339,241,012	5	323,250,602	355,231,423
15-20	161,885,592	5	153,505,182	170,266,002
20-25	78,638,294	6	73,912,573	83,364,014
25-30	34,293,734	8	31,659,379	36,928,090
30-35	14,072,296	11	12,491,933	15,652,659
35-40	6,035,058	16	5,064,876	7,005,241
>= 40	3,342,669	25	2,518,452	4,166,887

Chapter 5: Basal Area

1. Total Basal Area by Dzongkhag

Dzongkhag	Basal area (m^2)	MoE (%)	Lower Limit	Upper Limit
Bumthang	5,904,576.11	2.36	6,584,054.48	5,225,097.74
Chhukha	4,630,198.51	1.35	5,274,616.64	3,985,780.38
Dagana	5,110,555.53	1.39	5,688,796.54	4,532,314.52
Gasa	1,751,285.24	1.91	2,175,576.85	1,326,993.62
Haa	4,885,084.17	2.26	5,623,440.19	4,146,728.15
Lhuentse	6,689,816.94	2.29	7,718,783.31	5,660,850.57
Mongar	5,884,277.76	1.41	6,629,052.54	5,139,502.99
Paro	2,417,184.77	2.33	2,885,008.42	1,949,361.12
Pemagatshel	2,078,019.36	1.49	2,367,826.37	1,788,212.34
Punakha	3,120,841.12	1.89	3,484,033.69	2,757,648.55
Samdrup Jongkhar	4,129,602.33	1.33	4,658,843.91	3,600,360.74
Samtse	2,371,391.70	1.94	2,726,518.17	2,016,265.24
Sarpang	4,215,900.35	1.54	4,728,965.87	3,702,834.84
Thimphu	2,989,309.08	2.35	3,536,192.01	2,442,426.14
Trashigang	5,652,557.64	2.05	6,364,538.44	4,940,576.85
Trashi Yangtse	3,223,215.35	2.34	3,720,689.81	2,725,740.88
Trongsa	5,704,010.57	1.82	6,531,204.42	4,876,816.73
Tsirang	1,367,627.88	1.83	1,614,602.24	1,120,653.53
Wangdue Phodrang	9,113,925.84	2.25	10,029,713.66	8,198,138.02
Zhemgang	7,090,080.67	1.13	7,685,758.14	6,494,403.19

2. Total Basal Area by Forest Type

Forest Type	Basal area (m^2)	MoE (%)	Lower Limit	Upper Limit
Blue Pine Forest	2,394,961.08	16.29	2,004,761.78	2,785,160.38
Chir Pine Forest	32,351,462.45	4.96	30,747,335.70	33,955,589.21
Cool Broadleaved Forest	1,187,117.44	17.83	975,426.39	1,398,808.50
Evergreen Oak Forest	1,547,650.39	23.72	1,180,528.18	1,914,772.60
Fir Forest	19,239,873.59	6.63	17,963,322.51	20,516,424.67
Hemlock Forest	6,065,091.96	14.79	5,167,847.99	6,962,335.94
Juniper Rhododendron Forest	1,069,332.06	29.65	752,301.46	1,386,362.66
Spruce Forest	1,560,611.25	20.16	1,245,978.00	1,875,244.50
Subtropical Forest	7,151,359.77	7.07	6,646,094.50	7,656,625.03
Warm Broadleaved Forest	18,501,525.79	5.89	17,412,524.55	19,590,527.03

3. Total Basal Area by Elevation

Elevation Class	Basal Area (m2)	MoE (%)	Lower Limit	Upper Limit
0- 1000	6,960,335.05	7.32	6,450,841.54	7,469,828.57
1000- 2000	20,225,183.34	5.66	19,081,305.83	21,369,060.85
2000-3000	35,516,127.50	4.95	33,758,865.61	37,273,389.39
3000-4000	24,620,644.76	6.38	23,049,111.77	26,192,177.76
>=4000	1,068,605.74	45.80	579,218.42	1,557,993.06

4. Total Basal Area by DBH Class

DBH Class	Basal area (m^2)	MoE (%)	Lower Limit	Upper Limit
10-20	8,485,661.50	4.18	8,131,029.34	8,840,293.65
20-30	9,902,922.76	4.06	9,500,505.71	10,305,339.81
30-40	10,467,087.31	4.12	10,035,475.80	10,898,698.83
40-50	9,757,251.59	4.68	9,301,056.07	10,213,447.11
50-60	8,995,977.73	5.65	8,487,999.11	9,503,956.34
60-70	8,049,580.37	6.38	7,536,087.25	8,563,073.49
70-80	6,900,280.53	7.36	6,392,730.23	7,407,830.83
80-90	6,474,308.12	8.48	5,925,134.84	7,023,481.41
90-100	4,867,807.36	10.23	4,369,655.28	5,365,959.43
=>100	13,734,455.50	10.19	12,334,305.61	15,134,605.39

5. Total Basal Area by Height Class

Height Class	Basal area (m^2)	MoE (%)	Lower Limit	Upper Limit
<5	758,553.25	13.99	864,656.46	652,450.04
5-10	9,428,765.78	5.53	9,949,877.63	8,907,653.93
10-15	17,709,027.03	4.92	18,579,842.12	16,838,211.95
15-20	19,084,396.65	5.15	20,066,760.35	18,102,032.96
20-25	17,566,969.55	6.54	18,715,675.49	16,418,263.60
25-30	11,939,387.06	8.44	12,947,016.72	10,931,757.39
30-35	6,075,238.05	11.94	6,800,438.92	5,350,037.17
35-40	2,915,555.63	16.86	3,407,100.85	2,424,010.41
=>40	2,157,439.76	26.33	2,725,483.59	1,589,395.92

6. Total Basal Area by species

Species	Basal Area per ha (m^2)	MoE (%)	Lower Limit	Upper Limit
Abies densa	4.84	14.57	4.14	5.55
Acer spp.	1.20	12.62	1.05	1.35
Ailanthus integrifolia	0.03	75.08	0.01	0.06
Alnus spp.	0.36	24.93	0.27	0.45
Aphanamixis polystachya	0.06	41.36	0.03	0.08
Beilschmiedia spp.	0.32	24.40	0.24	0.39
Betula spp.	0.65	16.23	0.54	0.76
Bombax ceiba	0.04	74.85	0.01	0.06
Castanopsis spp.	1.42	15.70	1.20	1.64
Cupressus spp.	0.06	157.36	-0.04	0.16
Duabanga grandiflora	0.12	41.38	0.07	0.17
Engelhardia spicata	0.29	24.18	0.22	0.37
Exbucklandia populnea	0.15	55.01	0.07	0.23
Juglans regia	0.04	52.50	0.02	0.06
Juniperus spp.	0.60	33.05	0.40	0.80
Larix griffithii	0.04	62.13	0.01	0.06
Magnolia spp.	0.32	25.42	0.24	0.40
Persea spp.	1.47	14.54	1.26	1.68
Phoebe goalparensis	0.04	72.31	0.01	0.06
Picea spinulosa	0.44	33.93	0.29	0.59
Pinus roxburghii	0.43	30.04	0.30	0.56
Pinus wallichiana	0.87	25.26	0.65	1.09
Quercus spp.	4.27	10.80	3.81	4.73
Rhododendron spp.	1.86	11.26	1.65	2.07
Schima wallichii	0.42	21.78	0.33	0.51
Sterculia villosa	0.05	45.17	0.03	0.08
Symplocos spp.	0.49	15.33	0.42	0.57
Taxus baccata	0.10	39.71	0.06	0.14
Terminalia myriocarpa	0.06	61.83	0.02	0.10
Tetrameles nudiflora	0.09	60.43	0.04	0.15
Toona ciliata	0.12	44.14	0.07	0.17
Tsuga dumosa	1.31	23.76	1.00	1.62
other	10.17	5.31	9.63	10.71

Chapter 6: Growing Stock and table

1. Total volume by Dzongkhag

Dzongkhag	Volume	MoE (%)	Lower Limit	Upper Limit
Bumthang	53774171.30	15.46	45458791.39	62089551.21
Chhukha	38985862.01	17.03	32348125.72	45623598.30
Dagana	41496131.50	14.32	35552161.56	47440101.44
Gasa	15139211.88	30.08	10585711.37	19692712.39
Haa	39558528.50	20.34	31513521.38	47603535.61
Lhuentse	62934148.09	20.28	50169713.54	75698582.64
Mongar	52225538.50	14.99	44398108.36	60052968.65
Paro	25216950.25	27.74	18220990.53	32212909.98
Pemagatshel	14641205.69	18.94	11868404.66	17414006.72
Punakha	25948991.18	18.35	21187444.78	30710537.57
Samdrup Jongkhar	37382783.65	17.21	30947620.67	43817946.63
Samtse	21741797.63	20.47	17290512.50	26193082.76
Sarpang	36288622.30	15.99	30486899.42	42090345.19
Thimphu	28821921.07	23.46	22059571.42	35584270.71
Trashigang	47035541.77	16.23	39402343.61	54668739.93
Trashi Yangtse	28529074.27	22.29	22169200.95	34888947.59
Trongsa	48430263.09	18.22	39605666.14	57254860.04
Tsirang	10262014.48	25.08	7688367.16	12835661.81
Wangdue Phodrang	77329722.84	14.42	66180411.59	88479034.08
Zhemgang	60045917.65	12.09	52786686.94	67305148.36

2. Total volume by Forest Type

Forest Type	Volume (m^3)	MoE (%)	Lower Limit	Upper Limit
Subtropical Forest	57,299,179.09	8.63	52,353,841.06	62,244,517.13
Chir Pine Forest	9,167,793.74	22.79	7,078,443.69	11,257,143.79
Warm Broadleaved Forest	152,479,152.29	7.32	141,310,203.65	163,648,100.93
Evergreen Oak Forests	13,863,410.89	30.03	9,700,655.16	18,026,166.62
Cool Broadleaved Forest	285,954,870.41	6.20	268,211,442.83	303,698,297.99
Blue Pine Forest	21,645,795.65	21.27	17,041,213.07	26,250,378.23
Spruce Forest	16,254,681.31	22.98	12,518,634.06	19,990,728.57
Hemlock Forest	57,731,630.86	17.98	47,352,871.77	68,110,389.96
Fir Forest	172,558,623.94	8.04	158,682,442.33	186,434,805.55
Juniper Rhododendron Forest	7,041,632.92	37.08	4,430,346.52	9,652,919.32

3. Total volume by Elevation

Elevation *(m.a.s.l)*	Volume	MoE(%)	Lower Limit	Upper Limit
<1000	55,118,824.85	9.81	49,712,839.53	60,524,810.18
1000-2000	163,835,818.40	7.69	151,232,021.21	176,439,615.59
2000-3000	318,667,333.15	6.90	296,686,753.18	340,647,913.13
3000-4000	225,007,494.54	8.35	206,224,310.74	243,790,678.33
>=4000	4,860,313.81	55.94	2,141,457.08	7,579,170.54

4. Total volume by DBH Class

DBH Class	Volume (m^3)	MoE(%)	Lower Limit	Upper Limit
10-20	41,465,200.72	4.43	39,627,838.91	43,302,562.53
20-30	61,423,703.03	4.40	58,719,161.57	64,128,244.50
30-40	76,178,021.62	4.34	72,870,385.65	79,485,657.60
40-50	80,936,202.13	5.00	76,892,874.68	84,979,529.58
50-60	80,175,210.10	5.94	75,416,607.32	84,933,812.89
60-70	79,116,578.81	6.90	73,661,330.04	84,571,827.58
70-80	70,459,466.25	7.87	64,911,232.91	76,007,699.60
80-90	66,904,844.48	8.93	60,929,640.67	72,880,048.30
90-100	51,500,694.39	10.73	45,975,843.41	57,025,545.37
>=100	151,046,278.31	10.95	134,506,492.75	167,586,063.88

5. Total volume by height class

Height Class (m)	Volume (m^3)	MoE(%)	Lower Limit	Upper Limit
<5	1,647,829.43	226,547.01	1,421,282.42	1,874,376.45
5-10	37,220,641.11	2,046,287.73	35,174,353.38	39,266,928.84
10-15	104,940,798.21	5,211,419.83	99,729,378.38	110,152,218.03
15-20	149,074,914.78	7,746,066.03	141,328,848.75	156,820,980.80
20-25	170,402,727.14	11,230,866.64	159,171,860.50	181,633,593.78
25-30	135,795,138.53	11,481,671.28	124,313,467.25	147,276,809.82
30-35	79,817,918.58	9,570,658.86	70,247,259.72	89,388,577.44
35-40	43,046,999.83	7,235,703.40	35,811,296.43	50,282,703.23
>= 40	37,259,232.25	10,242,119.00	27,017,113.25	47,501,351.26

6. Volume per ha by species

Species	Volume ($m^3 ha^{-1}$)	MoE (%)	Lower Limit	Upper Limit
Abies densa	47.21	14.84	40.20	54.22
Acer spp.	10.26	13.79	8.85	11.68

Ailanthus integrifolia	0.31	74.78	0.08	0.54
Alnus spp.	3.39	26.37	2.50	4.28
Aphanamixis polystachya	0.46	53.65	0.21	0.70
Beilschmiedia spp.	2.71	25.57	2.02	3.40
Betula spp.	5.92	17.81	4.86	6.97
Bombax ceiba	0.40	82.13	0.07	0.74
Castanopsis spp.	12.60	16.73	10.49	14.71
Cupressus spp.	1.21	171.36	-0.86	3.29
Duabanga grandiflora	1.26	48.18	0.65	1.86
Engelhardtia spicata	2.75	25.73	2.04	3.45
Exbucklandia populnea	1.65	60.83	0.64	2.65
Juglans regia	0.40	53.81	0.18	0.61
Juniperus spp.	4.02	35.52	2.59	5.45
Larix griffithii	0.33	67.11	0.11	0.56
Magnolia spp.	2.69	27.35	1.96	3.43
Persea spp.	13.16	15.40	11.13	15.19
Phoebe goalparensis	0.34	76.42	0.08	0.60
Picea spinulosa	5.39	37.09	3.39	7.39
Pinus roxburghii	3.54	32.78	2.38	4.70
Pinus wallichiana	8.88	27.35	6.45	11.31
Quercus spp.	43.20	11.87	38.08	48.33
Rhododendron spp.	10.00	12.26	8.77	11.22
Schima wallichii	3.54	23.61	2.71	4.38
Sterculia villosa	0.46	50.17	0.23	0.68
Symplocos spp.	2.95	18.13	2.41	3.48
Taxus baccata	0.66	39.97	0.40	0.93
Terminalia myriocarpa	0.86	69.11	0.26	1.45
Tetrameles nudiflora	0.87	57.86	0.36	1.37
Tsuga dumosa	13.68	24.58	10.32	17.04
Others	78.52	6.32	73.56	83.48

7. Basal Area Increment

1. Total BAI by Dzongkhag

Dzongkhag	BAI (m^2yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Bumthang	57,143.45	38.26	35,281.45	79,005.44
Chhukha	65,458.19	45.21	35,865.85	95,050.53
Dagana	79,943.29	20.75	63,352.15	96,534.43
Gasa	13,094.80	31.60	8,957.20	17,232.39

Haa	38,548.62	36.15	24,611.51	52,485.74
Lhuentse	32,783.76	68.66	10,274.70	55,292.82
Mongar	69,932.31	56.69	30,284.85	109,579.77
Paro	44,046.45	49.66	22,173.84	65,919.07
Pemagatshel	91,085.62	72.57	24,982.15	157,189.08
Punakha	50,831.38	30.25	35,453.75	66,209.00
Samdrup Jongkhar	76,506.29	25.76	56,801.08	96,211.51
Samtse	32,462.60	29.56	22,868.08	42,057.11
Sarpang	62,167.99	26.13	45,922.87	78,413.12
Thimphu	39,571.02	29.56	27,872.08	51,269.95
Trashigang	81,420.61	26.91	59,514.04	103,327.17
Trashi Yangtse	35,017.73	42.54	20,121.78	49,913.67
Trongsa	42,630.01	36.72	26,978.17	58,281.86
Tsirang	33,302.33	29.86	23,357.76	43,246.89
Wangdue Phodrang	86,966.68	23.48	66,548.23	107,385.13
Zhemgang	167,089.95	37.60	104,265.94	229,913.97

2. Total BAI by Forest Type

Forest Type	BAI (m^2 yr^{-1})	MoE (%)	Lower Limit	Upper Limit
Subtropical Forest	191791.49	27.43	139174.95	244408.03
Chir Pine Forest	21942.55	54.87	9901.68	33983.43
Warm Broadleaved Forest	356549.48	19.29	287782.57	425316.39
Evergreen Oak Forests	8004.59	79.36	1652.44	14356.74
Cool Broadleaved Forest	302487.42	13.08	262916.43	342058.42
Blue Pine Forest	70802.68	41.86	41161.78	100443.58
Spruce Forest	23365.17	73.07	6292.38	40437.96
Hemlock Forest	55577.74	41.02	32777.62	78377.85
Fir Forest	174638.17	24.26	132262.67	217013.68
Juniper Rhododendron Forest	9877.49	59.64	3986.71	15768.27

3. Total BAI by Elevation

Elevation	BAI (m^2 yr^{-1})	MoE (%)	Lower Limit	Upper Limit
<1000	191,522.93	28.57	136800.15	246245.71
1000-2000	403,401.74	19.57	324442.82	482360.67
2000-3000	383,013.60	14.64	326925.08	439102.11
3000-4000	244,645.74	18.35	199743.46	289548.03
>=4000	6,213.90	58.62	2571.11	9856.70

4. BAI per ha by Species

Species	BAI (m^2 $ha^{-1}yr^{-1}$)	MoE (%)	Lower Limit	Upper Limit
Abies densa	0.00582	36.837	0.00368	0.00797
Acer spp.	0.00309	35.574	0.00199	0.00419
Ailanthus integrifolia	0.00013	122.772	(0.00003)	0.00029
Alnus spp.	0.00163	70.394	0.00048	0.00278
Aphanamixis polystachya	0.00013	150.024	(0.00007)	0.00034
Beilschmiedia spp.	0.00132	48.783	0.00067	0.00196
Betula spp.	0.00176	64.610	0.00062	0.00290
Castanopsis spp.	0.00463	62.263	0.00175	0.00752
Cupressus spp.	0.00015	200.000	(0.00015)	0.00045
Duabanga grandiflora	0.00002	200.000	(0.00002)	0.00007
Engelhardia spicata	0.00198	68.814	0.00062	0.00335
Exbucklandia populnea	0.00051	81.417	0.00009	0.00092
Juglans regia	0.00021	181.026	(0.00017)	0.00058
Juniperus spp.	0.00173	59.586	0.00070	0.00276
Larix griffithii	0.00007	188.725	(0.00006)	0.00020
Magnolia spp.	0.00045	83.654	0.00007	0.00082
Persea spp.	0.00284	30.035	0.00199	0.00369
Phoebe goalparensis	0.00010	143.398	(0.00005)	0.00025
Picea spinulosa	0.00153	70.411	0.00045	0.00261
Pinus roxburghii	0.00066	82.642	0.00011	0.00120
Pinus wallichiana	0.00433	70.957	0.00126	0.00741
Quercus spp.	0.00711	44.705	0.00393	0.01029
Rhododendron spp.	0.00580	29.523	0.00408	0.00751
Schima wallichii	0.00185	44.336	0.00103	0.00266
Sterculia villosa	0.00008	200.000	(0.00008)	0.00025
Symplocos spp.	0.00202	38.618	0.00124	0.00279
Taxus baccata	0.00014	114.401	(0.00002)	0.00030
Terminalia myriocarpa	0.00011	200.000	(0.00011)	0.00033
Tetrameles nudiflora	0.00050	200.000	(0.00050)	0.00150
Tsuga dumosa	0.00214	66.474	0.00072	0.00356
Others	0.03877	13.650	0.03348	0.04406

16 ANNEXURE

16.1 List of Volume equations

SL No.	Species	Volume	Region
1	*Abies densa*	exp((-0.919947 + 1.859733* log (D) + 0.907633 * log (H))	WN
2	*Abies densa*	exp((-1.38883 + 1.77028 * log (D) + 1.04424 * log (H))	CE
3	*Abies densa*	exp((-1.38883 + 1.77028 * log (D) + 1.04424 * log (H))	S
4	*Acer*spp.	exp((-0.59555 + 2.02481* log (D) +0.854745* log (H))	WN
5	*Acer*spp.	0.03873 + 0.36273 * D^2 * (H)	CE
6	*Acer*spp.	0.03873 + 0.36273 * D^2 * (H)	S
7	*Ailanthus integrifolia*	(-1.94825 + 1.7273 * log(D) + 1.1669 * log(H)	S
8	*Alnus* spp.	exp((-0.565323 + 1.984601 * log (D) + 0.822937 * log (H))	S
9	*Aphanomixis polystachya*	(-0.09768 + 0.01051* H + 0.31875 * D^2 * (H)	S
10	*Beilschmiedia*	exp((-565323 + 1.984601 * log (D) + 0.822937 * log (H))	S
11	*Betula* spp.	exp((-0.46151 + 2.039844 * log (D) + 0.837461* log (H))	WN
12	*Betula* spp.	exp((-0.46151 + 2.039844 * log (D) + 0.837461 * log (H))	CE
13	*Betula* spp.	exp((-0.46151 + 2.039844 * log (D) + 0.837461 * log (H))	S
14	*Bombax ceiba*	exp((-0.70448 + 2.13777 * log (D) + 0.91127 * log (H))	S
15	*Castanopsis* spp.	(-0.00794 + 0.34759 * D^2 * (H)	CE
16	*Castanopsis spp.*	(-0.00794 + 0.34759 * D^2 * (H)	S
17	*Cupressus* spp.	exp((-0.565323 + 1.984601* log (D) + 0.822937* log (H))	WN
18	*Duabanga grandiflora*	(-0.565323 + 1.984601* log(D) + 0.822937 * log(H)	S
19	*Engelharatia spicata*	exp((-0.14969 + 2.1532* log (D) + 0.76463 * log (H))	CE
20	*Engelharatia spicata*	exp((-0.14969 + 2.1532* log (D) + 0.76463 * log (H))	S
21	*Juniperus*spp.	exp((-0.565323 + 1.984601* log (D) + 0.822937* log (H))	WN
22	*Larix griffithiana*	exp((-1.409685+ 1.846742 * log (D) + 1.045675 * log (H))	WN
23	*Michelia & Alcimandra*	0.00667 + 0.32947 * D^2 * (H)	CE
24	*Michelia & Alcimandra*	0.00667 + 0.32947 * D^2 * (H)	S
25	*Persea* spp.	exp((-0.56664 + 2.03335 * log (D) + 0.87279 * log (H))	CE
26	*Persea* spp.	exp((-0.56664 + 2.03335 * log (D) + 0.87279 * log (H))	S
27	*Phoebe hainesiana*	(-0.0432 + 0.3622 * D^2 * (H)	CE
28	*Phoebe hainesiana*	(-0.0432 + 0.3622 * D^2 * (H)	S
29	*Picea spinulosa*	exp((-1.29816 + 1.86384 * log (D) + 1.03333 * log (H))	CE

30	*Picea spinulosa*	exp((-1.29816 + 1.86384 * log (D) + 1.03333 * log (H))	S
31	*Picea spinulosa(dbh >75 cm)*	exp((-1.074891+ 1.893688* log (D) + 0.973121* log (H))	WN
32	*Picea spinulosa(dbh< =75 cm)*	exp((-1.074891+ 1.893688* log (D) + 0.973121* log (H))	WN
33	*Pinus roxburghii*	exp((-1.251652 + 1.964424 * log (D) + 1.003778 * log (H))	WN
34	*Pinus roxburghii*	(-0.00156 + 0.32159 * D^2 * (H)	S
35	*Pinus wallichiana*	exp((-1.049334+ 1.926332 * log (D) + 0.967612* log (H))	WN
36	*Pinus wallichiana*	exp((-1.049334 + 1.926332 * log (D) + 0.967612 * log (H))	CE
37	*Quercus* spp.	0.002111 + 0.392382 * D^2 * (H)	CE
38	*Quercus* spp.	0.002111 + 0.392382 * D^2 * (H)	S
39	*Quercus* spp.*(dbh <= 79 cm)*	0.00211 + 0.392382 * D^2 * (H)	WN
40	*Quercus* spp.*(dbh > 79 cm)*	0.002111 + 0.392382 * D^2 * (H)	WN
41	Rest of species	exp((-0.565323+ 1.984601* log (D) + 0.822937* log (H))	WN
42	Rest of species	exp((-565323 + 1.984601 * log (D) + 0.822937 * log (H))	S
43	*Rhododendron* spp.	exp((-0.565323+ 1.984601* log (D) +0.822937 * log (H))	CE
44	*Schima wallichi*	(-0.565323 + 1.984601 * log(D) + 0.822937 * log(H)	S
45	*Sterculia villosa*	0.00231 + 0.34018* D^2 * (H)	S
46	*Symplocos spicata*	0.00155 + 0.34028 * D^2 * (H)	CE
47	*Symplocos spicata*	0.00155 + 0.34028 * D^2 * (H)	S
48	*Terminalia myriocarpa*	(0.00635 + 0.35936* D^2 * (H)	S
49	*Tetrameles nudiflora*	(-1.3361 + 1.75959 * log(D) +0.99492 * log(H)	S
50	*Tsuga dumosa*	exp((-1.409685+ 1.846742 * log (D) + 1.045675 * log (H))	WN
51	*Tsuga dumosa*	exp((-1.409685 + 1.846742 * log (D) + 1.045675 * log (H))	CE
52	*Tsuga dumosa*	exp((-1.409685 + 1.846742 * log (D) + 1.045675 * log (H))	S

16.2 List of NFI 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	Tsedhar	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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