National Forest Inventory Report

Stocktaking Nation's Forest Resources

Volume II

Department of Forests and Park Services

MINISTER

སོ་ནམ་དང་ནགས་ཚལ་ལྷན་ཁག།

ROYAL GOVERNMENT OF BHUTAN
Ministry of Agriculture and Forests
Tashichhodzong
Thimphu, Bhutan

MESSAGE

I congratulate the Department of Forests and Park Services for coming up with the second volume of National Forest Inventory report. Together with the first volume, we now have a comprehensive picture of our forests in Bhutan that allows us to understand our forests beyond forest cover. I am very much excited to learn of our forest carbon stock which is estimated to be 709 million tonnes of carbon and realize that this estimate is the first ever field-based national estimate, which can monitored over time. This information is found to be timely and would be valuable for fulfilling our commitment to remain carbon neutral.

National forest inventory has gained global importance and momentum with countries striving to monitor their forest resources with the intention to mitigate climate change. It has become a requisite exercise under MRV component of REDD Readiness mechanism and now with the completion of NFI, Bhutan has made a significant step towards being REDD Ready. These are the evidence that Bhutan is committed towards fulfilling our responsibility to global community in addressing climate change.

In fact, I am happy to learn that the Department of Forest and Park Services has also established the Forest Reference Emission Level for Bhutan, wherein the national forest inventory provided much of the country-specific information required to estimate our emissions from forest. With the publication of this second report, we have established the baseline for reported parameters and I am confident that we would be able to pursue periodic inventory to monitor the changes in our resources for sustainable utilization without compromising our effort on conservation.

Therefore, I would like to commend the efforts and hard work of our colleagues in the Department of Forests and Park Services, particularly those involved in NFI as field crew and coordinating team in Forest Resources Management Division.

Hence, as I congratulate the team for this achievement, I hope the results and estimates presented in this report will be useful to wide range of user stakeholders aside from the policy makers.

Tashi Delek

Yeshey Dorji
Minister

SECRETARY

སོ་ནམ་དང་ནགས་ཚལ་ལྷན་ཁག།

ROYAL GOVERNMENT OF BHUTAN
Ministry of Agriculture and Forests
Tashichhodzong
Thimphu, Bhutan

MESSAGE

I am pleased to inform that the Department of Forest and Park Services is bringing out a comprehensive report on biomass and carbon stock in Bhutan's forests in light of increasing impact of climate change.

Forestry is an important part in Bhutan's efforts on climate change mitigation and adaptation Bhutan has committed to remain carbon neutral in 2009 and reaffirmed her commitment through Nationally Determined Contribution submitted to United Nations Framework Convention on Climate Change (UNFCCC) in 2016.

Conservation Forest is fundamental to sustainable development, from their role as carbon sinks and the vital ecosystem services they perform, to the many wood-based products and renewable energy they provide. Monitoring the status of forests to ensure their sustainable management is therefore essential if these benefits for the environment and for societies are to be maintained for future generations. Therefore, the assessment and estimation of forest biomass and carbon becomes a yardstick to measure our achievement towards the climate change commitments and planning our forest management interventions. Therefore, I am sure that this report will provide the baseline information and help in communicating our effort to global community in our effort of conserving our rich natural heritage.

Under the dynamic leadership of our Monarchs, Bhutan, despite being a very small country with limited financial resources, has been able to uphold and showcase our commitment for conservation of forest resources. The successful completion of NFI and the publication of this report is a testimony to our commitment to the conservation of environment.

Hence, I would like to congratulate the Department in general and NFI team in particular including field crew for this commendable work.

I am sure that the NFI will be of immense help to all stakeholders apart from the DoFPS and the Ministry.

Tashi Delek

Rinzin Dorji
Secretary

དཔལ་ལྡན་འབྲུག་གཞུང་། སོ་ནམ་དང་ནགས་ཚལ་ལྷན་ཁག།
ནགས་ཚལ་དང་སྐྱིད་ཀྱི་ཞབས་ཏོག་ལས་ཁུངས།

ROYAL GOVERNMENT OF BHUTAN
MINISTRY OF AGRICULTURE AND FORESTS
DEPARTMENT OF FORESTS AND PARK SERVICES
THIMPHU: BHUTAN

DIRECTOR

FOREWORD

Forests are our national resources and heritage which play an important role in the lives of Bhutanese people. Department of Forests was the first government department to be established in 1952 and.since it's establishment, the forestry department has been striving to conserve and manage Bhutan's forest resources & biodiversity to ensure social, economic and environmental well-being, and to maintain a minimum of 60% of the land under forest cover for all times to come sustain Bhutan's forest resources & biodiversity for the happiness of present and future generations. Our vision is to sustain Bhutan's forest resources & biodiversity for the happiness of present and future generations.

Therefore, one of our foremost efforts has been on monitoring forest resources over time for which we have been working hard to establish a robust data management system for managing the forestry information. Besides sound policies and legal framework, we need systematic collection of data and information on forest resources and its utilization over time, so that our forest management is evidence–based grounded in concrete data.

It gives me great pride in knowing that we have now successfully completed the national forest inventory and are publishing these reports; establishing baseline information required for sustainable forest management. These are the building–blocks required by the forestry sector in fulfilling our services in being able to sustain both tangible and intangible benefits of the forests for the growing needs of the people.

Therefore, let me congratulate and commend the Forest Resources Management Division (FRMD) for coming up with the second volume of National Forest Inventory Report which establishes the baseline data on many attributes of our forest resources that had not been done before. I look forward to continuing this endeavor into the future and carry out the next national forest inventory to be able to monitor the change in forest resources for informed policy-decisions and management strategies.

Once again, I would like to commend the work of dedicated team of young officers in FRMD led by Mr. Lobzang Dorji, Chief Forestry Officer for coordinating and carrying out the first NFI for Bhutan. My heartfelt thanks to the NFI crew, with whose hard work and perseverance, we have been able to complete the national forest inventory.

Tashi Delek!

Phento Tshering
Director

ACKNOWLEDGEMENT

The National Forest Inventory (NFI) of Bhutan has been successfully conducted with the concerted effort of many people. Had it not been for their unwavering support and commitment, carrying out NFI would have remained a distant dream and plan for the Department. Therefore, everyone associated with NFI, either directly or indirectly deserves to be acknowledged.

Firstly, the Ministry of Agriculture and Forests (MoAF) and the Department of Forests Park Services (DoFPS) merit a special mention here. Both the Ministry and Department recognized the importance of NFI; and provided guidance and necessary support from the inception of NFI in 2009 till the completion.

NFI also received guidance and advice from NFI Core team chaired by Hon'ble Secretary, Ministry of Agriculture and Forests. Their inputs have been invaluable to make some critical decisions in taking NFI forward.

NFI is a very expensive exercise requiring a lot of technical expertise. We greatly acknowledge the USDA Forest Service Experts; Professor Timothy Gordon Gregoire, Yale University, USA; Dr. Moe Maung Myint, the then Research Scientist, Yale University, USA Mr. Stefano Ricci, Software Engineer, FAO and Mino Togna, Software Engineer, FAO for their valuable inputs in terms of statistics, data management, computer programming and data analytical softwares.

Their expert inputs and contributions have been critical to see through NFI. Special thanks to Dr. Javier Garcia Perez, Statistician, FAO without whose technical assistance, this report could not have been published. We are thankful for the time that he has devoted in analyzing our data and building the technical capacity of the team in FRMD .

Besides the external technical support, this second report could not have reported the estimates without the technical support and commitment of collaborating agencies in carrying out parallel exercises crucial for generating the desired results and estimates.

The forest carbon estimates would not have been complete, had it not been for the unwavering support of Mr. Jamyang, Specialist and his team at Soil and Plant Analytical Laboratory in carrying out laboratory analysis of the soil and plant samples for carbon and biomass. Together, we have successfully collected, for the first time, a national data on soil organic carbon which will be of immense value for future studies as well.

The credit for successful collaboration also goes to Ms. Karma Dema, Program Director of National Soil Servcie Centre of Department of Agriculture for welcoming the collaboration and providing the support through the process.

Estimation of tree biomass and carbon has been possible only because of the hard work put in by UWICER in developing the allometric biomass models. The entire team working on biomass model , namely Mr. Yograj Chettri, Mr. Kuenzang Dendup, Mr. Madan Kumar Lama, Mr. Pema Thinley, Mr. Harka Bahadur Raika, Mr. Prem Bahadur Rai, Mr. Dorji Dukpa, Mr. Tshewang Dorji, Mr. Sangay, Mr. Kuenga Thinley for their hard work in developing the country-specific biomass models.

Estimation of annual increment of our forest at national level is being reported for the first time. This has been possible due to the laboratory support of UWICER, especially Mr. Karma Tenzin and his team in measuring more than 3000 tree cores collected from NFI.

Most importantly, we would like to acknowledge the hard work of the NFI field crew members and especially Mr. Langa Tshering, senior crew leader whom we lost to a tragic accident during field work. They have worked under difficult terrain and harsh weather conditions risking their own lives. From the commencement of field work in 2012, they have been in the field toiling under sun and rain; and at times spent time in the forest without food or water. For all these they deserve a special mention here. Their family members too deserve appreciation for continued support and for motivating them.

NFI is very intensive even in terms of financial inputs. Over the last 7 years since its inception in 2009 with preparatory phase, financial support was received from various donors and sponsors for different aspects of NFI:

- Netherlands Development Agency (SNV) for the technical assistance in inventory designing and piloting
- Bhutan Trust Fund for Environment Conservation for supporting the preparatory phase and initiating the Enumeration phase in Paro
- European Union (EU) through Renewable Natural Resources (RNR) Sector Support Programme (EU-RNR SSP) for supporting the field enumeration
- European Union (EU) through Global Climate Change Alliance (GCCA) for supporting the capacity building of NFI field crews
- FAO through the United Nations Reducing Emission from Deforestation and Forest Degradation Targeted Support program (UN REDD-TS) for supporting the institutional capacity building
- UNDP through Low Emission Capacity Building project (LECB) for supporting HR capacity building in forest carbon assessment
- Forest Carbon Partnership Facility (FCPF) for the World Bank facilitated REDD Readiness Project that has supported field enumeration and continues to support the remaining activities of NFI and NFMS
- Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), Germany, fund being delivered through ICIMOD in partnership with GIZ for supporting the forest carbon assessment field works under the on-going REDD+ Himalayas Project. This report is being printed under this project and with the support of REDD Readiness Project.

Therefore, entire amalgamation of aforementioned donors, experts including NFI field crew and Coordinating team are acknowledged sincerely for their support. Their contributions in terms of technical, financial and hard works are recorded deep in the hearts of many. They have been part of the Department's history and another milestone achieved.

Lastly, but not the least, the contribution of the Ms. Kinley Dem, Sr. Forestry Officer of FRMD, Dr. Jigme Tenzin, Dy Chief Forestry Officer of Watershed Management Division and Mr. Ugyen Penjor, Sr. Forestry Officer of Nature Conservation Division in putting together this report deserves special mention and appreciation, for rendering their expertise and time in drafting this report and adding value and meaning to the figures and estimates.

Forest Resources Management Division

EXECUTIVE SUMMARY

Nearly thirty years after the Pre-Investment Survey (PIS), carried out from 1974-81, the current National Forest Inventory (NFI) was launched with preparatory phase in 2009 and actual field work carried out between July, 2012 - December, 2015. Following the completion of field enumeration, data analysis was carried out in phased manner and results are being reported in two volumes. The first volume was published in 2016 and reported on the forest cover and growing stock (tree count, basal area and volume).

This second volume reports on biomass and forest carbon stock of the country, regeneration and increment status, species diversity , forest health and disturbance and predictions of wildlife habitat based on presence-absence record.

Scope, History and Methodology

- The estimates are reported at national level and then for different categories of interest such as by Dzongkhag, by forest type and by elevation.
- The national estimate has higher precision with lower margin of error and the precision decreases as the estimates are calculated at smaller sampling size (e.g Dzongkhag, forest type).
- NFI data were collected from a systematic cluster samples comprising of **2424** cluster plots laid at 4 Km x 4Km grid spread across the country. Each cluster plot comprised of three plots called Elbow (L), North (N) and East (E) laid at 50 meters apart forming a L-shaped sample plot.
- The tree biomass and carbon estimates are generated by applying biomass models on the tree data collected from cluster plots.
- The biomass and carbon of forest understory and organic carbon in soil were estimated based on samples collected from the plots laid 20 meters south west of cluster plot center.
- **1685** of the total **2424** cluster plots were enumerated during field enumeration out of which 339 plots were sampled for forest understory and soil carbon.
- All trees having a minimum diameter at breast height (DBH) of 10 cm were enumerated.
- More than 3500 trees were cored for tree cores to estimate the annual increment
- The data management and analysis was performed using Open Foris Collect and customized R-modules.

Biomass and carbon at national level

- The biomass density of forests is estimated to be 410 t/ha resulting in total biomass of forests of 1109 million tonnes. This corresponds to 521 million tonnes of carbon at 192 t/ha.
- The soil organic carbon (SOC) constitute 188 million tonnes of carbon with a per hectare estimate of 64 t/ha.
- The total forest carbon stock stored in vegetative carbon pool and soil comes to 709 million tonnes of carbon.
- The biomass and carbon density greater in forest than non-forest.
- The total biomass and biomass density increases with increasing DBH class and attends maximum at mid DBH class of 60-70 cm for total biomass (59 million tonnes) and 60-70, 80-80 and 80-90 in case of biomass density (21 t/ha).
- The AGB of 28 important species constitute more than 2/3 of the total tree AGB
- Soil Organic Carbon (SOC) diminishes with increasing soil depth. The total SOC stock at 0-10cm depth is 77 million tonnes, followed by 60 million tonnes in 10-20cm depth and 51 million tonnes in 20-30cm depth.

Biomass and carbon by Dzongkhag

- Trashigang Dzongkhag has the greatest total biomass with 96 million tonnes while Gasa has the lowest with 7 million tonnes. This corresponds to 45 million tonnes of carbon and 3 million tonnes of carbon in Trashigang and Gasa respectively.
- The total SOC stock is greatest in Trashigang with 6 million tonnes and least in Paro with 2 million tonnes of SOC.
- However, the SOC density (t/ha) is found to be greatest in Tsirang with 197 t/ha and least in Pemagatshel with 45 t/ha.

Biomass and carbon by forest type

- The total biomass stock is greater in broadleaf forest with 726 million tonnes than conifer forest of 329 million tonnes of biomass. This corresponds to 341 million tonnes of carbon and 155 million tonnes of carbon in broadleaf and conifer forest respectively.
- The biomass density (t/ha) is greater in conifer forest than broadleaf forest with 486 t/ha and 380 t/ha respectively.
- Forest when segregated into the forest types defined as per Flora of Bhutan, Volume II, and cool broad-leaved forest has the greatest biomass stock of 500 million tonnes and dry-alpine scrub has the least biomass stock of 0.12 million tonnes.
- The total SOC content is greatest in broadleaf forest and least in conifer forest. Broadleaf forest contains 134 ± 16 million tonnes of SOC while conifer forest has 51 ± 11 million tonnes of carbon.
- SOC density is slightly greater in conifer forest than in broadleaf forest with 66 t/ha and 64 t/ha respectively.
- Amongst the 11 forest categories, total SOC ranks highest in cool broad-leaved forest with 74 million tonnes and least in evergreen oak forest with 2 million tonnes.
- The SOC density is however greatest in blue pine forest with 87 t/ha and least in sub-tropical forest with 36 t/ha.

Biomass and carbon by elevation

- The total biomass stock is greatest in 2000-3000 m elevation range with 540 million tonnes of biomass and least at elevation greater than 4000 m with 144 million tonnes of biomass. This corresponds to 254 million tonnes of carbon for forest in 2000-3000 m elevation and 68 million tonnes of carbon above 4000 m elevation.
- The biomass density is also greatest at 2000-3000 m with 497 t/ha and lowest at elevation greater than 4000 m with 3 t/ha.
- 2000-3000 m elevation also has the greatest total SOC stock with 67 million tonnes of carbon while the least is found in elevation lower than 1000 m with 17 million tonnes of SOC.
- SOC density follows total SOC stock and ranges between 18 t/ha and 36 t/ha in less than 1000 m and 2000-3000 m elevation respectively.

Regeneration

- Regeneration is categorized into recruits, un-established and established.
- On an average, 746 no/ha of recruits, 674 no/ha of un-established regeneration and 1240 no/ha of established is estimated in forest.
- Regeneration of recruits is higher in forest than in non-forest.
- Established regeneration is higher in non-forest than forest.
- By forest type, conifer forest has greater number of recruits per hectare than broadleaf forest with 1583 no/ha and 426 no/ha respectively. However, the number of un-established and established regeneration is not very different between the two.
- Overall, the conifer species (except Larix) dominates the regeneration in all three categories in both forests and non-forests areas

Increment

- Annual basal area increment per hectare in forest and non-forest is 0.48 m^2/ ha and 0.27 m^2/ha respectively.
- Annual Above ground biomass increment per hectare is estimated to be 2.01 t/ha and 1.25 t/ha in forest and non-forest.
- The annual BAI per hectare by Dzonkhags ranges from 0.13 – 0.69 m^2/ha. The lowest is in Gasa and greatest in Chukha.
- Broadleaf forest has slightly greater BAI than conifer forests with 0.51 m^2/ha /year and 0.41 m^2/ha/year respectively.
- It is greatest in the warm broad-leaved forest and at an elevation of 1000-2000m

Species diversity

- A total of 463 tree species were recorded through NFI. 448 species were recorded in forests while 250 species were recorded in non-forest.
- Highest number of species is recorded (220)Gasa (42)
- The species diversity (Shannon index) ranges from 0.69 (Thimphu) to 1.53 (Sarpang).
- The species diversity is greater in broadleaf forest than in conifer forest.
-
- Species diversity index by elevation ranges from 0.21 to 1.33 and shows a decreasing trend with increase in elevation.

Forest health and disturbance

- Forest faces greater risk from mistletoe infection than bark beetle infection
- Anthropogenic disturbances are found mostly in and around human settlements and roads.

Non Wood Forest Produce

- 12 genus of bamboos were recorded by NFI enumeration
- *Bambusa* and *Dendrocalamus* species are found mostly in southern regions while Yushania species are mostly found in northern regions
- The evidences show canes are found in warmer regions
- NFI has recorded 76 medicinal plants of different life forms (trees, shrubs and herbs)

Wildlife

- The presence-absence data of NFI could generate occupancy maps of nine large mammals , namely, Barking deer, Asiatic Black bear, Bluesheep, Elephant, Gaur, Golden Langur, Goral, Rhesus Macaque, Serow and Wild boar.
- These occupancy maps conforms to their known existing habitats.

ACRONYMS AND ABBREVIATIONS

.dbf	Database file
.ssf	Standard storage file
ABAI	Annual Basal Area Increment
AGB	Above-ground Biomass
AGBI	Above-ground Biomass Increment
BA	Basal Area
BAI	Basal Area Increment
BGB	Below-ground Biomass
BMUB	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
BTFEC	Bhutan Trust Fund for Environmental Conservation
CI	Confidence Interval
cm	Centimeter
DBH	Diameter at Breast Height
DoFPS	Department of Forests and Park Services
DOM	Dead Organic Matter
EU	European Union
FAO	Food and Agriculture Organization
FCPF	Forest Carbon Partnership Facility
FRMD	Forest Resources Management Division
GCCA	Global Climate Change Alliance
GCF	Global Forest Change
GI	Galvanized Iron
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit - German Corporation for International Cooperation
GPS	Global Positioning System
GS	Growing Stock
Ha	Hectare (unit of area)
ICIMOD	International Centre for Integrated Mountain Development
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
Km	Kilometer
LECB	Low Emission Capacity Building Project
m3	Cubic meter (unit of volume measurement)
mt	million tonnes
MoAF	Ministry of Agriculture and Forests
MoE	Margin of Error
NCD	Nature Conservation Division
NFI	National Forest Inventory
NFMS	National Forest Monitoring System
NFP	National Forest Policy

NPP	Net Primary Productivity
NSSC	National Soil Service Centre
PIS	Pre-Investment Survey
PWS	Phibsoo Wildlife Sanctuary
REDD	Reducing Emission from Deforestation and Degradation of forests
RGoB	Royal Government of Bhutan
RMNP	Royal Manas National Park
RNR SSP	Renewable Natural Resources Sector Support Programme
R-PP	REDD Readiness Project
RS	Remote Sensing
SOC	Soil Organic Carbon
SNV	Netherlands Development Agency
SRTM	Shuttle Radar Topography Mission
t/ha	tonnes per hectare
UN REDD -TS	UN REDD Targeted Support
UN	United Nations
WB	World Bank

Abbreviations for forest types

BPFr	Blue Pine Forest
CPFr	Chirpine Forest
DASc	Dry Alpine Scrub
EOFR	Evergreen Oak Forest
FIFr	Fir Forest
HMFr	Hemlock Forest
JUSc	Juniper Rhododendron Scrub
SPFr	Spruce Forest
STFr	ubtropical Forests
WBFr	Warm Broad-leaved Forests

CONTENTS

MESSAGE FROM MINISTER....I
MESSAGE FROM SECRETARY III
FOREWORD BY DIRECTOR....V
ACKNOWLEDGEMENT....VII
EXECUTIVE SUMMARY XI
ACRONYMS AND ABBREVIATIONS....XV

CHAPTER 1: BACKGROUND 1

1.1 Scope of National Forest Inventory (NFI) report II 1
1.2 Current NFI 1
1.3 Sampling design 2
1.4 Data Management....4

Data Collection 4
Data conversion and migration....4
Data sorting and cleaning....4
Data analysis....5

1.5 Limitation of the estimates 6

CHAPTER 2: FOREST BIOMASS AND CARBON....7

2.1 Forest Biomass and Carbon estimates at National Level 8

2.1.1 Total Biomass and Forest Carbon Stock....8
2.1.2 Biomass and carbon density....9
2.1.3. Biomass and carbon estimates by DBH Class....10
2.1.4 Biomass and carbon estimates for important species 11
2.1.5 Soil organic carbon (SOC) estimates at National level....13
2.1.6 Discussion....15

2.2 Forest Biomass and carbon estimates by Dzongkhag 16

2.2.1 Total biomass and carbon estimates by Dzongkhag 16
2.2.2 Biomass and carbon density by Dzongkhag 19
2.2.3 Soil organic carbon estimates by Dzongkhag 21
2.2.4 Discussion....23

2.3 Forest Biomass and Carbon estimates by forest type 24

2.3.1 The biomass and carbon estimate by forest type 24
2.3.2 Soil organic carbon by forest type 30
2.3.3 Discussion 34

2.4 Forest Biomass and Carbon estimates by elevation 35

2.4.1 Biomass and carbon by elevation 35
2.4.2 Soil organic carbon by elevation 38
2.4.3 Discussion 39

CHAPTER 3: REGENERATION AND INCREMENT 42

3.1 Regeneration 42

3.1.1 Regeneration at the national level 42
3.1.2 Regeneration by Dzongkhags 43
3.1.3 Regeneration by forest type 45
3.1.4 Regeneration by elevation 47
3.1.5 Regeneration by species 47
3.1.6 Discussion 51

3.2 Forest increment 52

3.2.1 Increment at national level 52
3.2.2 Increment by Dzongkhag 53
3.2.3 Increment by forest type 53
3.2.4 Increment by elevation 55
3.2.5 Increment by species 55
3.2.6 Discussion 57

CHAPTER 4: SPECIES DIVERSITY 61

4.1 Species diversity and composition at the National Level 62
4.2 Species diversity by forest and non-forest area 64
4.3 Species diversity by Dzongkhag 64
4.4 Species diversity by forest type 66
4.5 Species diversity by elevation 67
4.6 Discussion 68

CHAPTER 5: FOREST HEALTH AND DISTURBANCE....71

5.1 Pests and diseases....72
5.2 Timber Harvesting....73
5.3 Grazing....74
5.4 Garbage /waste....75
5.5 Discussion....75

CHAPTER 6: NON-WOOD FOREST PRODUCE....77

6.1 Bamboos....77
6.2 Canes....79
6.3 Medicinal plants....80

CHAPTER 7: WILDLIFE....85

7.1 Methodology....85
7.2 Results....86
7.3 Discussion....92

CHAPTER 8: WAY FORWARD....93

Reference....95
Appendix 1: Estimates of Biomass and Carbon....101
Appendix 2: Soil Organic Carbon Estimates....106
Appendix 3: Species diversity....109
Appendix 4: Regeneration....112
Appendix 5: Annual Increment....117
Appendix 6: Biomass models....120
Annexure I: List of National Forest Inventory Team Members....121
Annexure II: Forest Type....124
Annexure III: Land Cover Category....127

LIST OF TABLES

Table 1: Overview of accessible and inaccessible cluster plots 5
Table 2: Biomass and carbon stock estimates of forest with ± margin of error at 90% confidence level 8
Table 3: Total Soil Organic Carbon (in million tonnes) by soil depth with ± margin of error at 90% confidence level 14
Table 4: Total Biomass and Carbon Stock with confidence interval and margin of error percent 17
Table 5: Biomass and carbon by its constituent pool in broadleaf and conifer forest 24
Table 6: Total biomass and carbon estimates by forest type 26
Table 7: Total biomass and carbon estimates by elevation range 35
Table 8: List of bamboo species recorded through NFI 77
Table 9 : List of medicinal trees recorded through NFI with total number of cluster plots with positive observation 81
Table 10: List of medicinal shrubs recorded through NFI with total number of cluster plots with positive observation 82
Table 11: List of medicinal herbs recorded through NFI with total number of cluster plots with positive observation 83
Table 12: Total biomass estimates (in million tonnes) by carbon pool constituents for forest and non-forest with ± margin of error at 90% confidence level 101
Table 13: Biomass density estimates (tonnes per hectare) by carbon pool constituents for forest and non-forest with ± margin of error at 90% confidence level 101
Table 14: Total biomass estimates (in million tonnes) by Dzongkhag with ± margin of error at 90% confidence level 101
Table 15: Biomass density estimates (tonnes per hectare) by Dzongkhag with ± margin of error at 90% confidence level 102
Table 16: Above-ground biomass estimates of total and density by DBH class with ± margin of error at 90% confidence level 103
Table 17: Above-ground biomass estimates of both total and density by species with ± margin of error at 90% confidence level 103
Table 18: Total Biomass estimates (in million tonnes) by forest type with ± margin of error at 90% confidence level 104
Table 19: Biomass density estimates (tonnes per hectare) by forest type with ± margin of error at 90% confidence level 104
Table 20: Total biomass estimates (in million tonnes) for Broadleaf and Conifer forest with ± margin of error at 90% confidence level 105
Table 21: Biomass density estimates (tonnes per hectare) for Broadleaf and Conifer forest with ± margin of error at 90% confidence level 105
Table 22: Total Biomass estimates (in million tonnes) by elevation range with ± margin of error at 90% confidence level 105
Table 23: Biomass density estimates (tonnes per hectare) by elevation range with ± margin of error at 90% confidence level 105
Table 24: Total Soil Organic Carbon estimates (in million tonnes) for forest and non-forest with ± margin of error at 90% confidence level 106
Table 25: Soil Organic Carbon density estimates (tonnes per hectare) for forest and non-forest with ± margin of error at 90% confidence level 106

Table 26: Total Soil Organic Carbon estimates (in million tonnes) by Dzongkhag with ± margin of error at 90% confidence level 106
Table 27: Soil organic carbon density estimates (tonnes per hectare) by Dzongkhag with ± margin of error at 90% confidence level 107
Table 28: Total Soil Organic Carbon estimates (in million tonnes) by Forest type with ± margin of error at 90% confidence level 107
Table 29: Soil Organic Carbon density (tonnes per hectare) by Forest type with ± margin of error at 90% confidence level 108
Table 30: Total Soil Organic Carbon estimates (in million tonnes) for broadleaf and conifer forest with ± margin of error at 90% confidence level 108
Table 31: Soil Organic Carbon density (tonnes per hectare) estimates for broadleaf and conifer forest with ± margin of error at 90% confidence level 108
Table 32: Total Soil Organic Carbon estimates (in million tonnes) by elevation with ± margin of error at 90% confidence level 108
Table 33: Soil Organic Carbon density estimates (tonnes per hectare) by elevation with ± margin of error at 90% confidence level 108
Table 34: Measures of tree species diversity 109
Table 35: Measures of tree species diversity for forest and non-forest 109
Table 36: Measures of tree species diversity by Dzongkhag 110
Table 37: Measures of species diversity for forest type categorized as Broadleaf forest and Conifer forest 111
Table 38: Measures of species diversity by elevation range 111
Table 39: Total Regeneration Count (in millions) estimates with ± margin of error at 90% confidence level for forest and non-forest 112
Table 40: Per hectare regeneration count for forest and non-forest with ± margin of error at 90% confidence level 112
Table 41: Total Regeneration Count estimates (in millions) by Dzongkhag with ± margin of error at 90% confidence level 112
Table 42: Per hectare regeneration count by Dzongkhag with ± margin of error at 90% confidence level 113
Table 43: Total regeneration count (in millions) by forest type with ± margin of error at 90% confidence level 113
Table 44: Per hectare regeneration count by forest type with ± margin of error at 90% confidence level 114
Table 45: Total regeneration count (in millions) in broadleaf and conifer forest with ± margin of error at 90% confidence level 114
Table 46: Per hectare regeneration count in broadleaf and conifer forest with ± margin of error at 90% confidence level 114
Table 47: Total regeneration count (in millions) by elevation range with ± margin of error at 90% confidence level 114
Table 48: Per hectare regeneration count by elevation with ± margin of error at 90% confidence level 115
Table 49: Total regeneration count (in millions) by species with ± margin of error at 90% confidence level 115
Table 50: Per hectare regeneration count by species with ± margin of error at 90% confidence level 116
Table 51: Annual Basal area increment for forest and non-forest with ± margin of error at 90% confidence level 117
Table 52: Annual Basal area increment(BAI) by Dzongkhag with ± margin of error at 90% confidence level 117

Table 53: Annual Basal area increment(BAI) in broadleaf and conifer forest with ± margin of error at 90% confidence level 118
Table 54: Annual Basal area increment (BAI) by elevation range with ± margin of error at 90% confidence level 118
Table 55: Annual Basal area increment by forest type with ± margin of error at 90% confidence level........ 118
Table 56: Annual basal area increment by species with ± margin of error at 90% confidence level........ 119
Table 57: Annual Above-ground biomass increment (AGBI) for forest and non-forest with ± margin of error at 90% confidence level 119
Table 58: Allometric biomass models 120

LIST OF FIGURES

Figure 1: NFI Plot Design with forest carbon plots 2
Figure 2: Above-ground forest understory and soil carbon plot........ 2
Figure 3 : Layout of 2424 Cluster plots........ 3
Figure 4 : Overview of accessible cluster plots 6
Figure 5: Total biomass by carbon pools........ 9
Figure 6: Total carbon stock by carbon pools........ 9
Figure 7: Biomass density in forest and non-forest with ± MoE at 90% confidence level 9
Figure 8: Carbon density in forest and non-forest with ± MoE at 90% confidence level 9
Figure 9: Biomass density by carbon pool constituents 10
Figure 10: Carbon density by carbon pool constituents........ 10
Figure 11: Total biomass estimates by DBH Class 11
Figure 12: Total carbon estimates by DBH Class 11
Figure 13: Biomass density (tonnes per hectare)by DBH class 11
Figure 14: Carbon density (tonnes per hectare) by DBH class 11
Figure 15: Total above-ground biomass (in million tonnes) of 28 major tree species........ 12
Figure 16: Above-ground biomass density (tonnes per ha) of 28 major tree species........ 13
Figure 17: Total SOC (in million tonnes) of soil for a depth of 30cm........ 14
Figure 18: SOC density(tonnes per ha) of soil for a depth of 30 cm 14
Figure 19: Total SOC by soil depth in forest and non-forest 15
Figure 20: SOC density by soil depth in forest and non-forest 15
Figure 21: Total biomass and carbon by Dzongkhag........ 16
Figure 22: Total biomass estimates of different carbon pools constituent by Dzongkhag........ 18
Figure 23: Biomass and carbon density by Dzongkhag........ 19
Figure 24: Biomass density of carbon pool constituents by Dzongkhag........ 20
Figure 25: Total Soil Organic Carbon estimates by Dzongkhag 21
Figure 26: SOC density of soil for a depth of 30cm 22
Figure 27: Total SOC by Dzongkhag at different soil depths........ 22
Figure 28: SOC density at different soil depth........ 23
Figure 29: Total biomass in broadleaf and conifer forest 24
Figure 30: Biomass density of broadleaf and conifer forest 25
Figure 31: Total biomass by carbon pool constituents 25
Figure 32: Total biomass by carbon pool constituents in conifer forest........ 25
Figure 33: Total carbon by carbon pool constituent in broadleaf forest 25
Figure 34: Total carbon by carbon pool constituent in conifer forest 25
Figure 35: Total biomass and forest carbon estimates by forest type........ 26
Figure 36: Total biomass estimates of carbon pool constituents by forest type 27
Figure 37: Biomass density by forest type 27
Figure 38: Biomass density of carbon pool constituents by forest type 29
Figure 39: Total SOC for a depth of 30 cm in broadleaf and conifer forest........ 30
Figure 40: SOC density for a depth of 30 cm in broadleaf and conifer forest 31
Figure 41: Comparing total SOC of broadleaf forest and conifer forest at different soil depth........ 31
Figure 42: Comparing SOC density of broadleaf forest and conifer forest at different soil depth 32
Figure 43: Total SOC within a depth of 30 cm for different forest types 32
Figure 44: SOC density for a depth of 30cm (tonnes per hectare) by forest type........ 33

Figure 45: Depth wise total SOC by forest type 33
Figure 46: Depth wise SOC density by forest type......34
Figure 47: Total biomass estimates by elevation range......36
Figure 48: Total carbon estimates by elevation......36
Figure 49: Total biomass estimates of the carbon pool constituents by elevation 36
Figure 50: Biomass density by elevation range......37
Figure 51: Carbon density by elevation range 37
Figure 52: Biomass density of carbon pool constituents by elevation......37
Figure 53: Total SOC within a depth of 30 cm by elevation 38
Figure 54: Comparison of total SOC at different soil depth at varying elevation range......38
Figure 55: SOC density within 30cm depth by elevation......39
Figure 56: Elevation wise SOC density at different soil depth......39
Figure 57: Total regeneration in forest and non-forest......42
Figure 58: Regeneration per hectare in forests and non-forest 43
Figure 59: Regeneration per hectare by Dzongkhag......44
Figure 60: Regeneration per hectare in broadleaf and conifer forest 45
Figure 61: Pattern of regeneration in different forest types 46
Figure 62: Regeneration per hectare at different elevations......47
Figure 63: Regeneration pattern of different species in forest and non-forest 48
Figure 64: Pattern of regeneration of different species in forest......49
Figure 65: Regeneration pattern of different species in non-forest 50
Figure 66: BAI per hectare in forest and non-forest 52
Figure 67: BAI per hectare by Dzongkhag......53
Figure 68 : BAI per hectare in broadleaf and conifer forest......54
Figure 69: BAI per hectare in different forest types......54
Figure 70: BAI per hectare at different elevations......55
Figure 71: BAI of major species in forest and non-forest......56
Figure 72: Observed and extrapolated number of species with SE for the country, forests and non-forests 62
Figure 73: Species accumulation curve for forest......63
Figure 74: Species accumulation curve for non-forest 63
Figure 75: Diversity indices of Shannon, Evenness and Beta for the overall Country, forests and non-forest......64
Figure 76: Diversity indices of Shannon, Evenness and Beta by Dzongkhag......65
Figure 77: Number of observed species and extrapolated species with SE by Dzongkhag 65
Figure 78: Number of observed and extrapolated species with SE in broadleaf and conifer forest......66
Figure 79: Diversity indices of Shannon, Evenness and Beta in broadleaf and conifer forest 66
Figure 80: Observed and extrapolated number of species with SE by elevation......67
Figure 81: Diversity indices of Shannon, Evenness and Beta of forests at different elevations......68
Figure 82: Map showing bark beetle and mistletoe infection recorded on NFI plots......72
Figure 83: Timber extraction recorded by NFI 73
Figure 84: Grazing evidence recorded by NFI......74
Figure 85: Evidence of garbage and waste materials recorded by NFI......75
Figure 86: Location of bamboos recorded by NFI 78
Figure 87: Spatial distribution of canes as recorded by NFI 79
Figure 88: Distribution of medicinal plants by its plant form 80
Figure 89: Distribution of medicinal trees recorded through NFI 81
Figure 90: Distribution of medicinal shrubs recorded through NFI......83
Figure 91: Distribution of medicinal herbs recorded through NFI 84

Figure 92: Predicted distribution of barking deer in Bhutan 86
Figure 93: Predicted distribution of Asiatic black bear in Bhutan 87
Figure 94: Predicted distribution of Blue sheep in Bhutan 87
Figure 95: Predicted distribution of Asian elephant in Bhutan 88
Figure 96: Predicted distribution of Gaur in Bhutan 88
Figure 97: Predicted distribution of Golden langur in Bhutan 89
Figure 98: Predicted distribution of Himalayan goral in Bhutan 89
Figure 99: Predicted distribution of Rhesus macaque in Bhutan 90
Figure 100: Predicted distribution of Himalayan serow in Bhutan 91
Figure 101: Predicted distribution of wild boar in Bhutan 91

CHAPTER 01
BACKGROUND

1.1 Scope of National Forest Inventory (NFI) report II

This report is the second volume of Bhutan's National Forest Inventory Report. The fieldwork began in July, 2012 and was completed in December, 2015. It also provides information on wider aspects forest resources and forest health in Bhutan that was not reported in Volume I. It includes:

- Forest biomass and carbon
- Species richness and diversity
- Growth and increment
- Forest health and disturbance
- Non-wood forest produce
- Wildlife

Volume I reported on forest cover and growing stock of forests in Bhutan. This volume, combined with the first volume, will present the comprehensive state of forest resources in Bhutan. This report intends to present the quantitative and qualitative analysis of the NFI data.

1.2 Current NFI

As opposed to traditional National Forest Inventories that focus mainly on timber resource assessments, the current NFI of Bhutan is a multipurpose forest ecosystem health monitoring inventory. Therefore, information on biodiversity, forest health (pest and disease), forest disturbance and soil carbon was collected.

The preparatory phase for the current national forest inventory began in 2009 and lasted until mid-2012. This phase involved developing the sampling design, piloting the sampling design, preparing field manuals, procuring field gear and equipment, and selecting and training NFI field crews.

The fieldwork for current NFI took three and half years to complete data collection from all twenty Dzongkhags. The main purpose of the current NFI is to generate updated information on forest resources of country which can then be used to support formulation of policies and legislations related to forest management, use and conservation as needed by various stakeholders and other line agencies.

1.3 Sampling design

The national forest inventory uses a systematic sampling cluster comprising of 2424 cluster plots arranged on a 4 km by 4 km grid spread across the country. The centre of all NFI plots are monumented with galvanized iron (GI) pipes for the purpose of relocating the plots for any future forest inventories.

Each cluster plot consists 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, North and East plot (Figure 1) and the layout of each of the 2424 cluster plots is illustrated in Figure 3

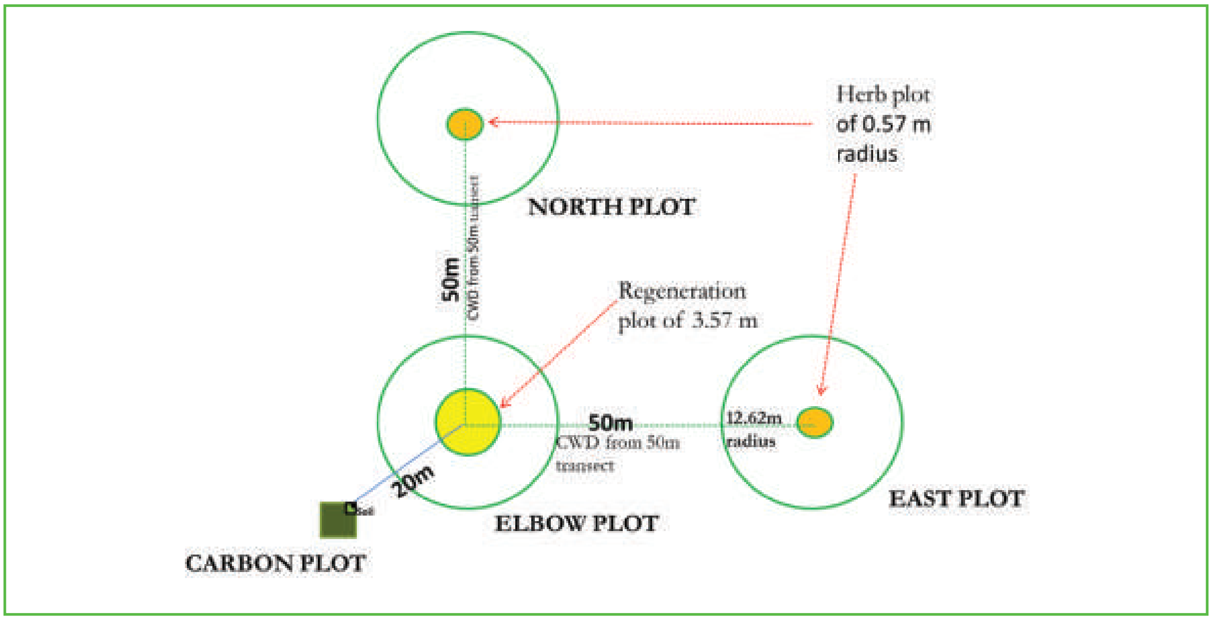


Figure 1: NFI Plot Design with forest carbon plots

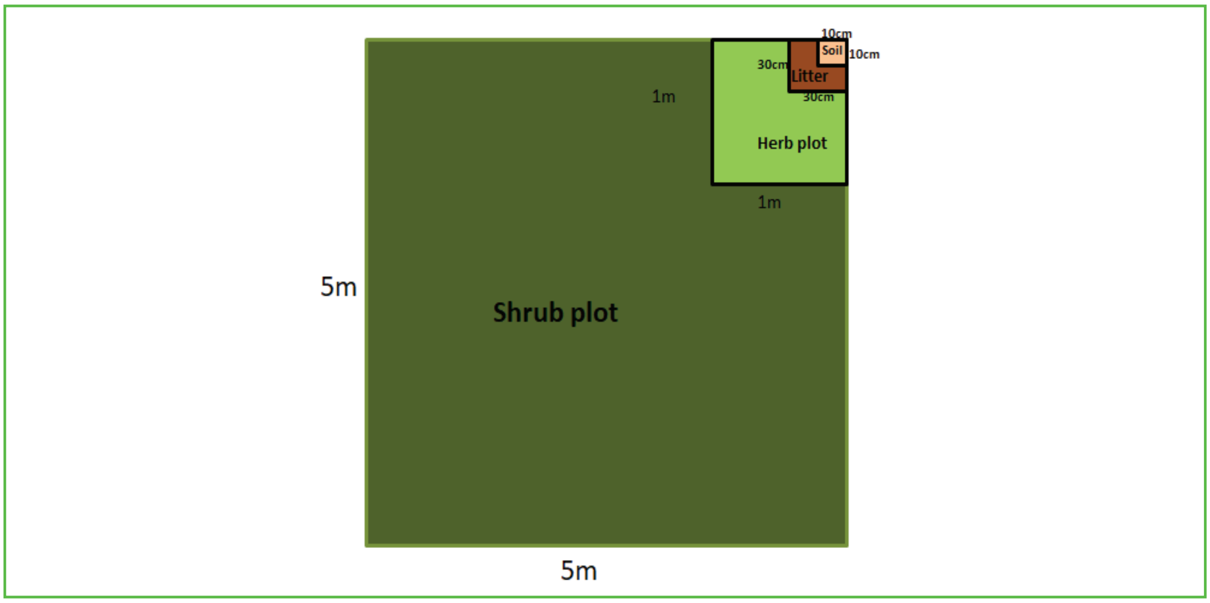


Figure 2: Above-ground forest understory and soil carbon plot

Therefore, all trees having a minimum DBH of 10 cm irrespective of their conditions are enumerated from the plots and counted as trees while those trees having DBH between 5- 10 cm were enumerated as saplings. Similarly, woody perennials without a definite crown and with minimum height of 0.5 m to a maximum height of 5 m were enumerated as 'shrubs'. For tree regeneration and herbs, smaller sub-plots were nested within the Elbow, East and North plots. A nested sub-plot of 3.57 m radius for regeneration was laid within the Elbow plot and 0.57 m radius sub-plots for herbs were laid within both the North & East plots.

Twenty meters south-west of the Elbow plot centre, the above-ground understory and soil carbon plots were laid for collecting samples of forest understory and soil. The above-ground understory and soil carbon plots consist of a 5 m by 5 m plot for destructive sampling of shrubs, a 1m by 1 m square plot for herbs, a 30 cm by 30 cm for litter and a 10 cm by 10 cm plot for soil. The above-ground understory and soil carbon plot is illustrated in Figure 2.

Although the cluster plot consists of three disjoint plots, it is treated as a single sampling unit in the analysis. For statistical purposes, the sampling population size of the NFI is expressed as N = 2424 sampling units distributed across Bhutan. However, only 20% of the cluster plots for each dzongkhag was selected and sampled for forest understory and soil carbon.

The details of the sampling design and field data collection methodology is described in detail in the Field Manual, National Forest Inventory of Bhutan and A field Guide, for Above-ground Understory and Soil Carbon Assessment, published by Forest Resources Management Division in 2012 and 2014, respectively.

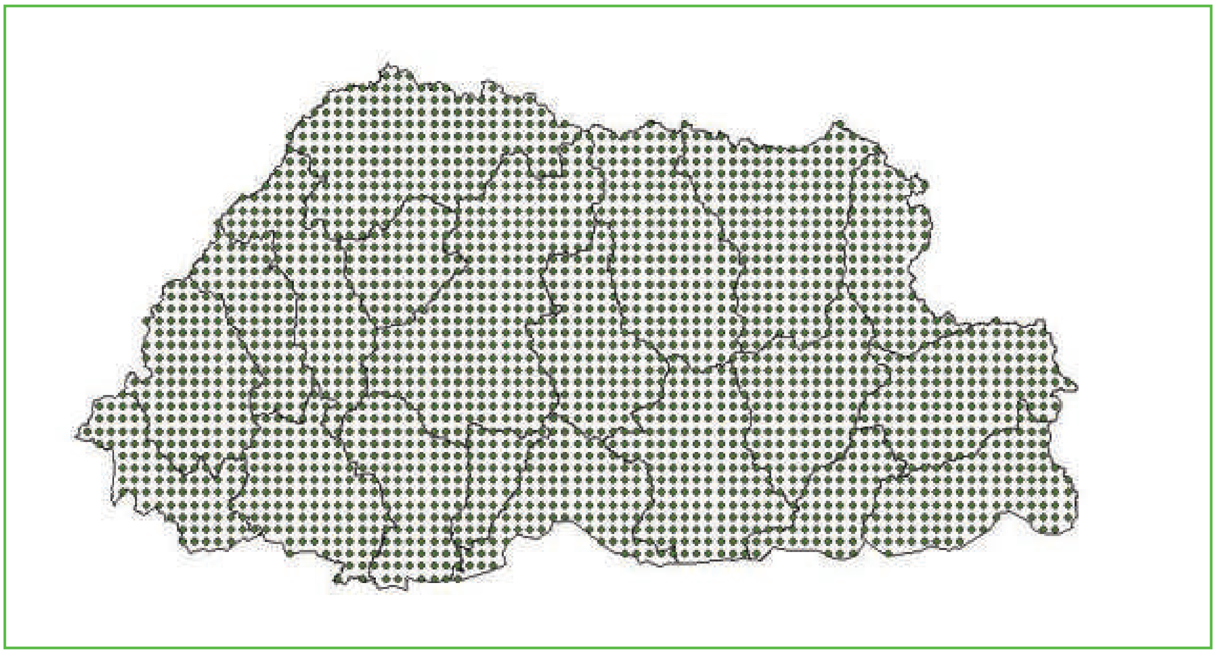


Figure 3 : Layout of 2424 Cluster plots

1.4 Data Management

This chapter briefly describes and presents the data flow from field data collection to statistical analysis and presentation.

Data Collection

The NFI data collection was done using Trimble Global Positioning System (GPS) device, which was used for navigation and for data logging. Upon completion of the enumeration of each cluster plot, the data is transferred to laptops and backed–up in external hard drives provided to the field crew for data security. Upon completing enumeration in each district, the data is transferred onto the centralized data server maintained at FRMD.

However, under unavoidable circumstances such as plot falling in valleys resulting into poor or no GPS signals and at the times when GPS drained out of battery, the information were recorded in paper forms. The data from paper forms were then later digitized at FRMD.

Data conversion and migration

The data collected using Trimble GPS are in standard storage file (.ssf) format. These were then converted into Database file (.dbf) format using Pathfinder Office software, to make it compatible with Open Foris Collect tools, which has been adopted for NFI data management. Open Foris Collect is an open source data management tool developed by FAO.

The converted files (.dbf) are then migrated to the Collect platform with the help of customized data migratory tool (software program) developed by FAO experts.

Data sorting and cleaning

The migrated data are then launched in the Collect platform. From Collect platform, the data are then exported as comma separated values (csv) files. These csv files are cleaned, sorted and prepared for final analysis.

The data validation is also executed in Collect platform with a set of validation rules developed in Collect survey design itself.

Data analysis

The NFI data analysis for the estimates and information presented in this volume have been carried out using R statistical program version 3.4.3. The maps presented in this report are prepared in Arc GIS 10.3.1 and QGIS 2.1.8. The graphs were prepared using Microsoft Office.

Of the total 2424 cluster plots, 1685 have been enumerated while the remaining 739 plots could not be accessed owing to various reasons, such as, security issues, difficult terrain, rivers, snow and glaciers. Out of the 1685 accessible cluster plots, 338 plots were enumerated for the forest understory and soil carbon assessments.

Table 1 shows the status of accessibility of cluster plots in each Dzongkhag while Figure 4 shows overview of accessible plots.

Table 1 : Overview of accessible and inaccessible cluster plots

SN	Dzongkhag	Total Plots	Accessible	Inaccessible	Accessibility (%)
1	Bumthang	167	126	41	75
2	Chukha	113	94	19	83
3	Dagana	107	93	14	87
4	Gasa	201	48	153	24
5	Haa	121	84	37	69
6	Lhuntse	181	64	117	35
7	Mongar	120	92	28	77
8	Paro	81	73	8	90
9	Pemagatshel	63	56	7	89
10	Punakha	70	51	19	73
11	Samdrup Jongkhar	119	100	19	84
12	Samtse	80	75	5	94
13	Sarpang	104	88	16	85
14	Thimphu	114	80	34	70
15	Trashigang	137	132	5	96
16	Trashiyangtse	90	58	32	64
17	Trongsa	113	73	40	65
18	Tsirang	42	41	1	98
19	Wangdue Phodrang	251	143	108	57
20	Zhemgang	150	114	36	76
	TOTAL	2424	1685	739	70

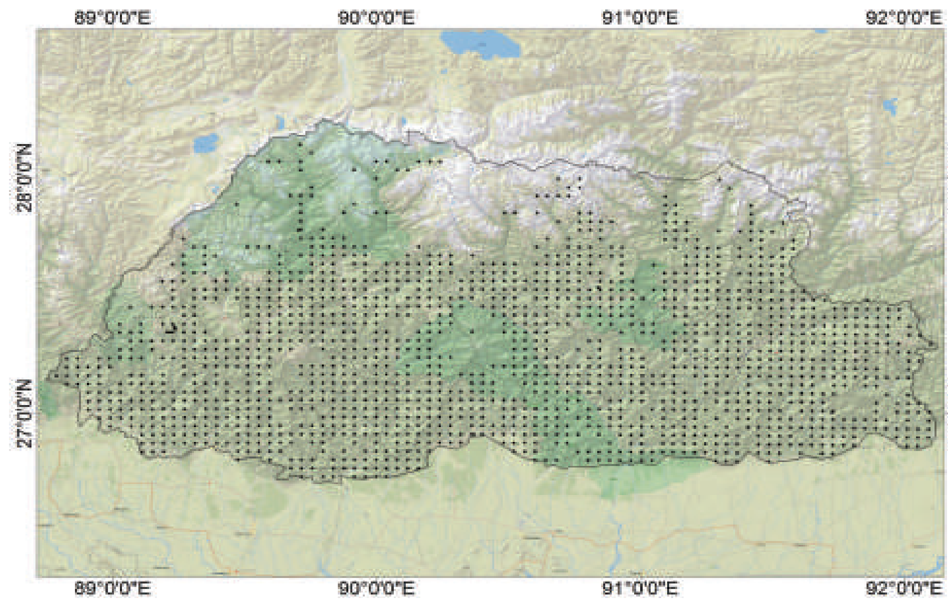


Figure 4 : Overview of accessible cluster plots

All statistical estimates presented in this report have been generated using NFI data and samples collected over the period of three and a half years and analyzed with the help of the R statistical program. Biomass and carbon analyses for the understory forest and soil samples were analyzed in the Soil and Plant Analytical Laboratory of National Soil Service Centre under Department of Agriculture, Ministry of Agriculture and Forests.

R modules have been developed with the help of FAO experts to enable customized data analysis and generation of NFI results for Bhutan. All resource estimates are generated at the cluster plot-level and are rounded to nearest whole number or sometimes to a maximum of three decimal places. The estimates are presented along with their margin of error (MoE). The results of the analyses are presented as individual chapters and detailed estimates are tabulated in the Appendix 1 to 5.

1.5 Limitation of the estimates

The current NFI has been designed to obtain estimates of basal area per hectare at a national level with precision at 15% margin of error at 90% confidence level. Therefore, the estimates generated at Dzongkhag level and other categories such as by forest types and major tree species will have lesser precision than estimates generated at the national level. Further, due to inaccessibility of 30% of the cluster plot, the desired precision for some categories may not be achieved. However, the estimates generated serve to provide a comparison among the categories and also provide an indication of relation between the parameter of interest and the category. For example, the estimates of above-ground biomass (AGB) by forest types provide means that can be used to explore potential relationships between AGB across different forest types.

CHAPTER 02
FOREST BIOMASS AND CARBON

Biomass and forest carbon stock assessment has gained importance in the recent years with forests serving as a significant terrestrial carbon sink. Deforestation and forest degradation account for approximately 17 percent of carbon emissions, more than the entire global transportation sector and second only to the energy sector (UN-REDD, 2018). Assessing forest carbon stock and changes over time is therefore important for mitigation and adaptation to the impacts of climate change . The forest biomass and carbon estimates can also be used for monitoring Net Primary Productivity (NPP) of our forest over time.

This chapter reports the estimates of biomass and carbon for all five carbon pools identified under Good Practice Guidance (IPCC, 2006). The carbon pool is comprised of above-ground biomass (AGB), below-ground biomass (BGB), dead organic matter consisting of litter and coarse woody debris and soil organic carbon. The estimates of total carbon stock from each pool are summed to obtain the total forest carbon stock of Bhutan. Estimates from all the pools except for below-ground biomass (BGB) are derived from actual field measured data. However BGB was determined by applying the root:shoot ratios presented by Mokany et al. (2006) to the AGB of trees and saplings.

BGB = 0.489 x AGB0.8

Sixteen biomass allometric models (presented in Table 58 Appendix 6), developed as a parallel exercise to NFI, were used to indirectly estimate the tree and sapling biomass, while the biomass of shrubs and herbs were based on direct measurements of oven-dried weights of the samples collected from NFI.

Carbon estimates of plant biomass were then calculated by applying a carbon:biomass fraction of 0.47 (IPCC, 2006) to the biomass estimates. However, for the soil organic carbon (SOC) estimates, the soil samples were analyzed in the laboratory for SOC content using the Walkley-Black method (Walkley and Black, 1934) along with the use of CHNS analyzer equipment.

These estimates are the first field-based data collected at a national level and serve as baseline information for monitoring the changes over time. The assessment of biomass and carbon within the pools and by categories such as elevation and forest types will be invaluable for carbon budgeting through forest management.

The carbon and biomass estimates are categorized by forest and non-forest, elevation and forest types. These different categories are presented at the country level as well as at the individual Dzongkhag levels.

NOTE: ***While the total carbon pool is comprised of all five carbon pools, the estimates of biomass do not include soil.***

The Above-ground biomass (ABG), Below-ground biomass (BGB) and Dead Organic Matter (DOM) have been categorised as the "vegetative carbon pool". In addition, the estimates of SOC are generally reported independently (with the exception at national level when it is included in the total forest carbon stock category). Therefore, the estimates of biomass and carbon reported by categories refers to estimates for the vegetative carbon pools only.

Also when specifically reporting the biomass estimates of trees, saplings, shrubs and herbs, these categories are referred to in this report as carbon pool 'constituents'.

2.1 Forest Biomass and Carbon estimates at National Level

2.1.1 Total Biomass and Forest Carbon Stock

The total biomass of our forests is estimated to be about 1109 million tonnes which translates to 521 million tonnes of carbon. The total forest carbon stock is estimated to be 709 million tonnes when including 188 million tonnes of carbon stored in forest soils as soil organic carbon (Table 2).

Table 2 : Biomass and carbon stock estimates of forest with ± margin of error at 90% confidence level

Carbon pools	Carbon Pool Constituent	Biomass (tonnes per ha)	Carbon (tonnes per hectare)	Total Biomass (million tonnes)	Total carbon (million tonnes)	Margin of Error (%)
Above ground Biomass	Trees	241 ± 14	113.74	657.15	308.86	6
	Shrubs	1.61 ± 0.27	0.7567	4.72	2.22	16
	Herbs	0.71 ± 0.15	0.3337	2.07	0.97	21
	Sapling	26 ± 10	12.22	72.31	33.99	39
Below Ground Biomass	Tree Roots	112 ± 5	50.29	290.78	136.67	5
	Sapling roots	9 ± 3	4.29	25.19	11.84	30
Dead Organic Matter	Litter	13.25 ± 2	6.2275	39.03	18.34	16
	Coarse woody Debris	6.44 ±3	3.0268	18.14	8.53	41
Soil	Soil(0-30cm depth)		64.07 ± 4.17		187.85	8
Total Forest carbon stock					**709.27**	**4**

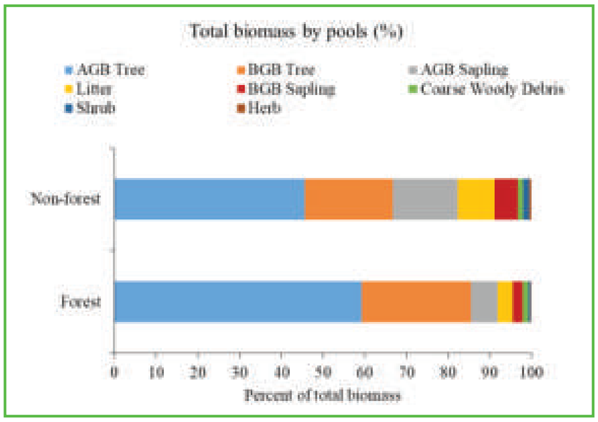


Figure 5: Total biomass by carbon pools

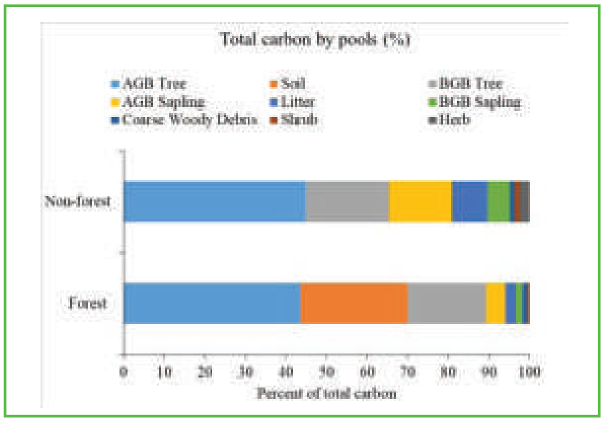


Figure 6: Total carbon stock by carbon pools

Among the five carbon pools, the above-ground tree biomass forms the major part of the forest carbon contributing nearly half of the total carbon in Bhutan's forest. The SOC constitutes 26% of the total forest carbon stock with 188 million tonnes of carbon closely followed by below-ground tree biomass with 137 million tonnes of carbon.(However it should be noted here that this SOC estimate is not the total soil carbon of the whole soil profile depth, but soil carbon to only a 30cm depth. Frequently studies find more carbon in the total soil profile than in its above-ground vegetation).The contribution of litter and coarse woody debris to forest carbon stock are 18 and 9 million tonnes, respectively, while understory forest carbon from herbs and shrubs is comparatively low proportionally, as compared to other pools (Figure 5 and 6)

2.1.2 Biomass and carbon density

The total biomass and carbon density of our forests are estimated to be about 410 ± 18 t/ha and 192 ± 17 t/ha (Figure 7), respectively, while that of non-forest land is 85 ± 11 t/ha and 40 ± 5 t/ha, respectively (Figure 8).

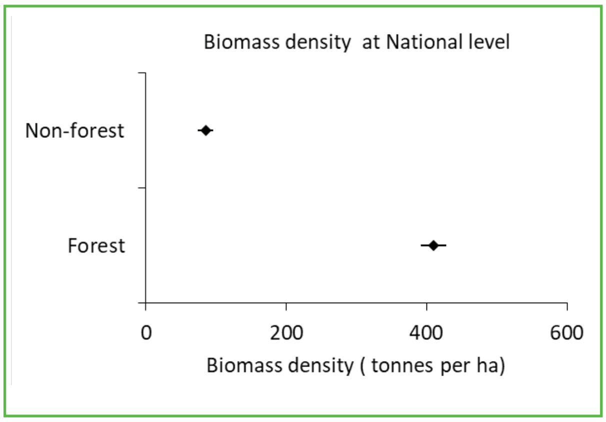


Figure 7: Biomass density in forest and non-forest with ± MoE(error bars) at 90% confidence level

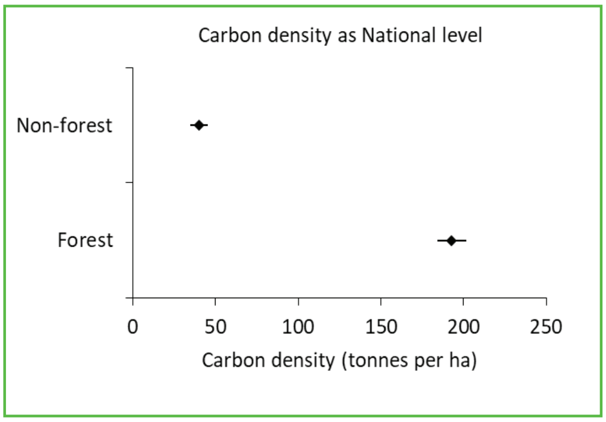


Figure 8 : Carbon density in forest and non-forest ± MoE(error bars) at 90% confidence level

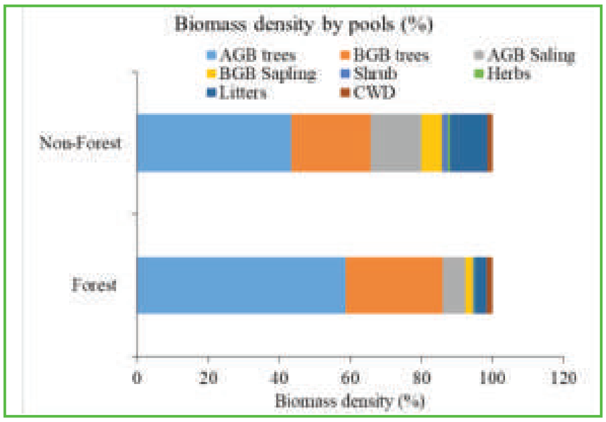


Figure 9 : Biomass density by carbon pool constituents

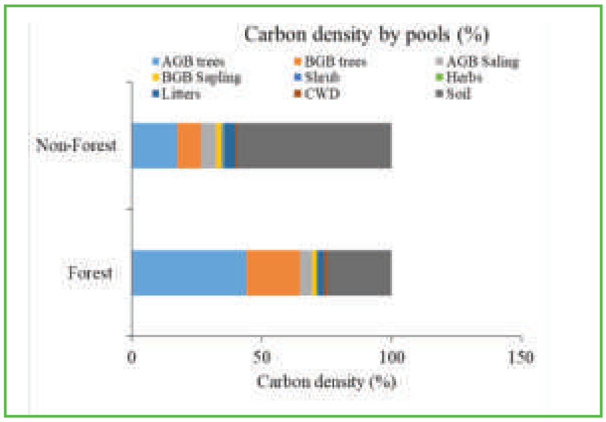


Figure 10: Carbon density by carbon pool constituents

The total biomass and biomass density (total carbon and carbon density) in the forest is much higher than the non-forest land. The forests account for large portion of terrestrial carbon (Mendoza-Ponce and Galicia, 2010; Sisay et al., 2017; Belay et al., 2018) relative to the terrestrial soil carbon pool (Petrokofsky et al., 2012) and subsequently play a very important role in global carbon cycle. Therefore, any land use change or conversion of forest land into non-forest land is likely to result in a loss of at least above-ground vegetative carbon which constitutes a major portion of the total carbon as found in Bhutan.

2.1.3. Biomass and carbon estimates by DBH Class

The total biomass and biomass density (and total carbon and carbon density) is estimated for nineteen diameter classes for above-ground tree carbon pool. The total above-ground biomass and carbon of trees increase with increasing diameter class and peaks at DBH class of 60-70 cm with 59 ± 3 and 28 ± 2 million tonnes but then decrease as DBH classes continue to increase (Figure 11 and 12). A similar trend is also observed in biomass and carbon density peaking at mid-diameter classes (Figure 13 and 14). With increasing tree diameters, the biomass and carbon increases, peaks at DBH 60 – 70 cm, and then gradually decreases (Figure 11 and 12) showing strong correlation with basal area which shows similar trend of increasing with DBH until 60-70 cm and decreasing gradually, as was reported in NFI Vol I. The highest biomass density is estimated to be 21 t/ha in DBH class of 60-70 and 80-90 cm while highest carbon density is estimated in DBH class of 60-70, 70-80 and 80-90 cm (refer Table 11 in Appendix 1). A similar trend in distribution of biomass by DBH class was also reported by Lin et al. (2014) in sub-tropical evergreen broad-leaved forest in China.

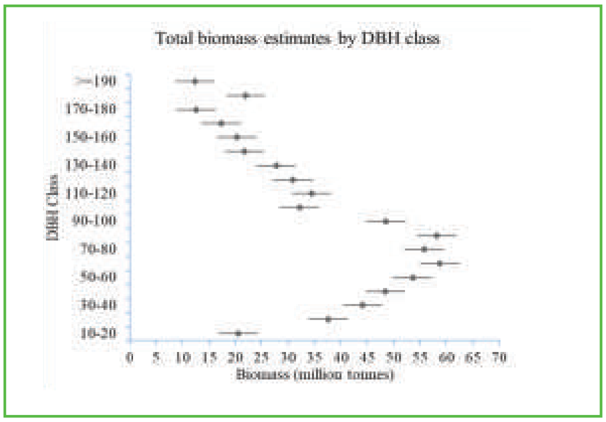


Figure 11: Total biomass estimates by DBH Class

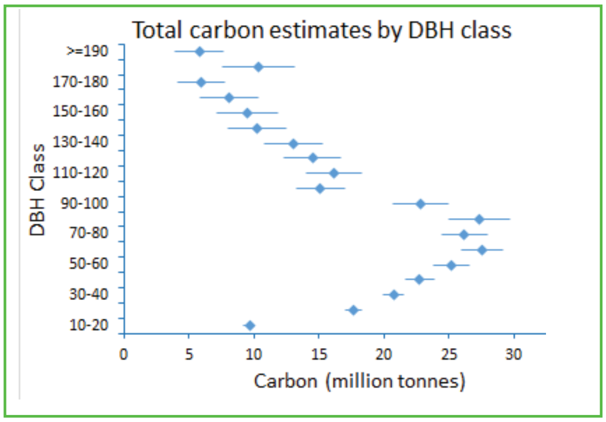


Figure 12: Total carbon estimates by DBH Class

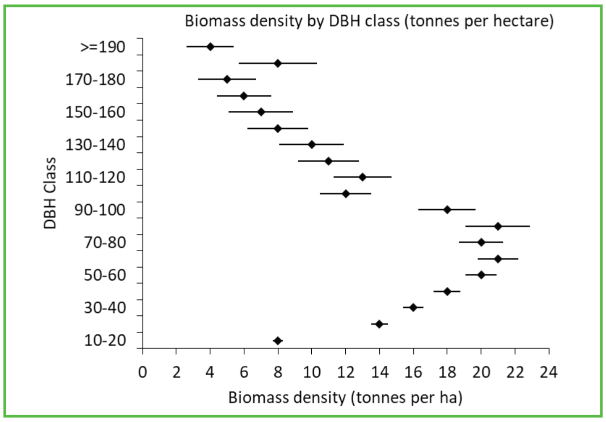


Figure 13: Biomass density (tonnes per hectare) by DBH class

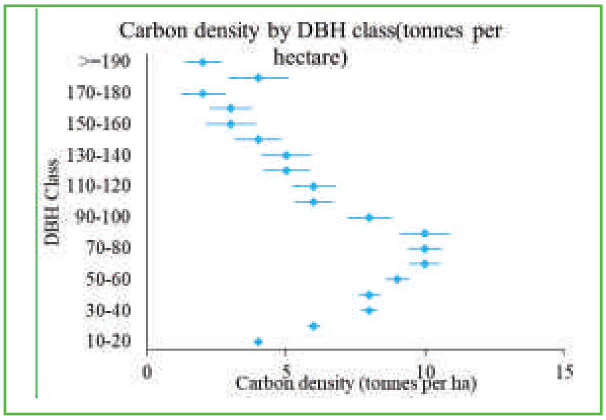


Figure 14: Carbon density (tonnes per ha) by DBH class

2.1.4 Biomass and carbon estimates for important species

Out of 460 plus tree species recorded during the NFI, the above-ground biomass (AGB) of 28 major genus of trees are reported individually and AGB of rest of the species reported as one estimate. Among the 28 major species, Quercus spp. has greatest total AGB of 112 million tonnes followed by Abies densa with total AGB of 85 million tonnes in forest areas. Cupressus spp. comprises of the least total AGB (at 0.01 million tonnes only) among the 28 major trees reported.

However, the per hectare estimates of Quercus spp. is only 127 t/ha whereas that of Abies densa is 216 t/ha. Phoebe hainesiana has the greatest density among the 28 major tree genus at 237 t/ha and the least AGB density to be that of Cupressus spp. with only 6 t/ha.

Based on the estimates, the 28 major trees may be inferred to be important source of biomass in Bhutan given that the sum of total AGB of these major trees are more than twice the total AGB of rest of the species. For detailed individual estimates with the margin of error at 90% confidence level, refer Table 17 of Appendix 1.

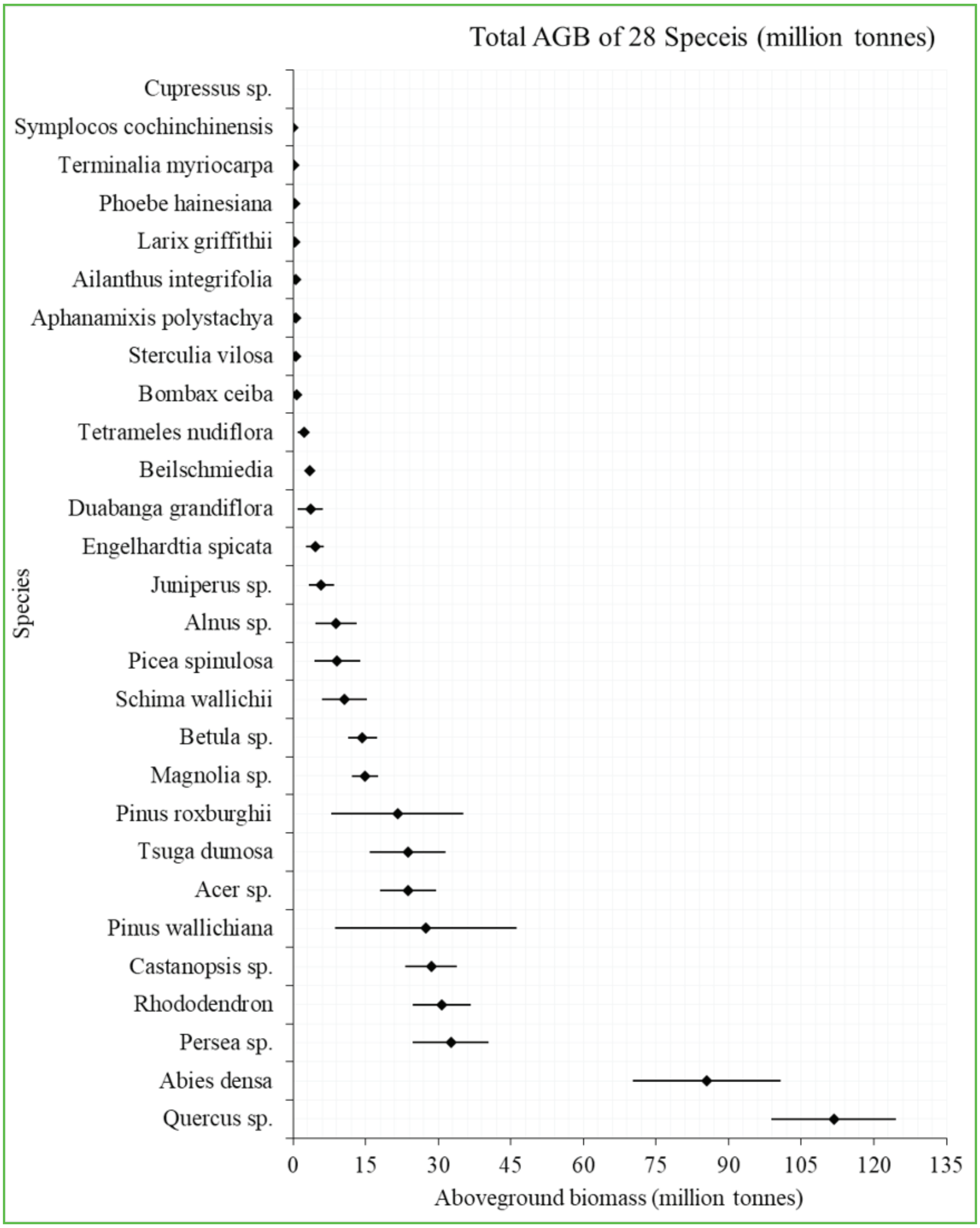


Figure 15: Total above-ground biomass (in million tonnes) of 28 major tree species

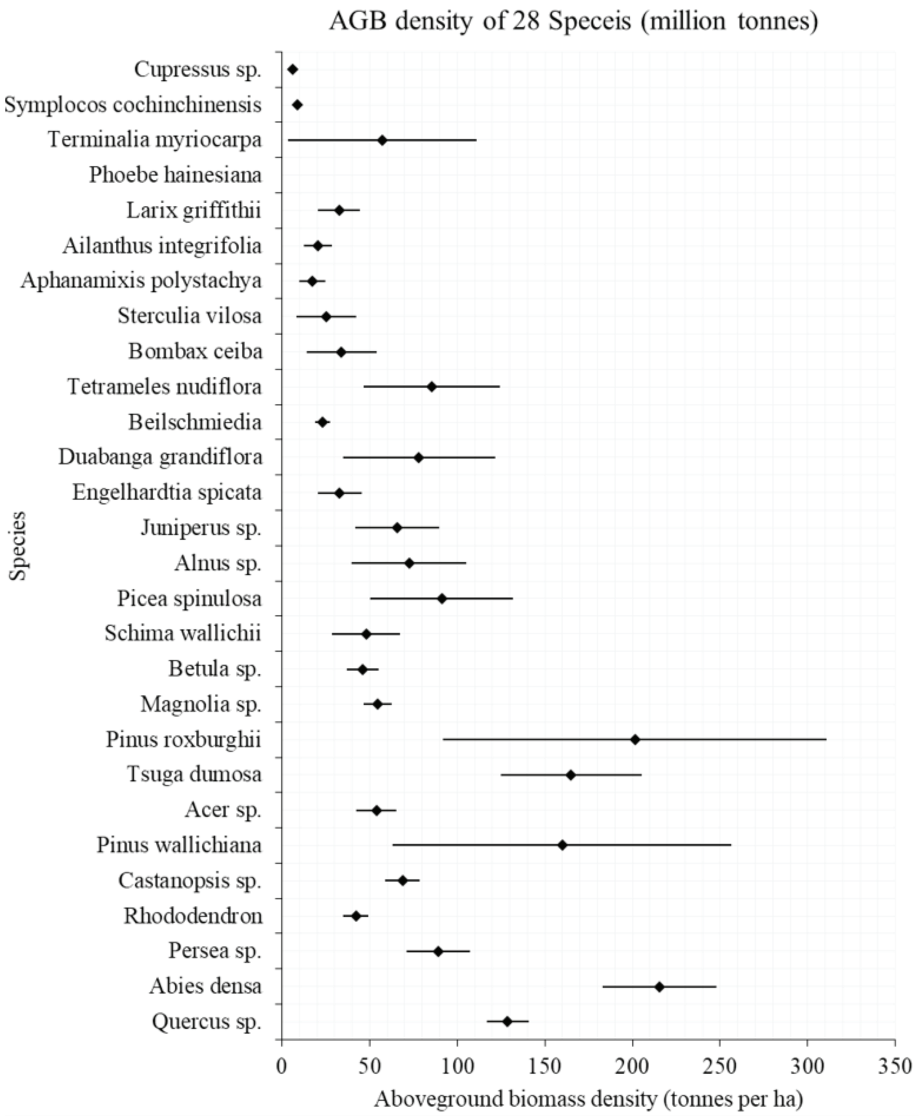


Figure 16: Above-ground biomass density (tonnes per ha) of 28 major tree species

2.1.5 Soil organic carbon (SOC) estimates at National level

Soil is a very important terrestrial organic carbon pool (Stergiadi et al., 2016; Yigini and Panagos, 2016) and therefore, the assessment of the soil organic carbon (SOC) has become more relevant with impacts of climate change and the scarcity of SOC estimates (Scharlemann et al., 2014). Similarly with the absence of adequate forest soil data in Bhutan, NFI was designed to collect soil samples to a depth of 30 cm using excavation method to provide baseline information on soil organic carbon in the forest soil.

The SOC estimates generated in this report are from samples collected from 331 NFI plots and analyzed for SOC content in the lab using Walkley-Black method (Walkley and Black, 1934) and CHNS analyzer.

The total soil organic carbon in Bhutan's forests are estimated to be 188 ± 16 million tonnes compared to 52 ± 10 million tonnes of carbon in non-forest land up to 30 cm depth of soil (Table 3 and Figure 17). As expected SOC content decreases with increasing soil depth (Figure 19 and 20). Total soil organic carbon content decreases significantly with increasing soil depth both in forested and non-forested lands. (Figure 20)

The forest lands have slightly higher SOC density compared to non-forest lands. The SOC density up to 30 cm depth of soil in our forests is 64 ± 4 t/ha while SOC density in non-forest land is 58 ± 6 t/ha. The SOC density estimates measured in the forests of Bhutan are within the reported global SOC density range of 25 t/ha to more than 300 t/ha (Scharlemann et al., 2014; NSSC, 2017).

The total SOC (to a depth of 30cm) constitutes 26% of total forest carbon stock of Bhutan which corresponds to 0.0125 % of 1500 giga tonnes of global SOC estimated for a depth of 1m (Scharlemann et al., 2014).

The estimates are also comparable with regional estimates of India 3,979 million tonnes of SOC and SOC density of 56.19 t/ha for 0-30 soil depth (FSI, 2017), SOC density of 59.35 t/ha in forested areas up to 0-60 cm soil depth in Pakistan (Ali et al., 2017) and modeled SOC density of 51.54 to 105.21 t /ha for different forest types in Bhutan (NSSC, 2017).

Table 3: Total Soil Organic Carbon (in million tonnes) by soil depth with ± margin of error at 90% confidence level

Category	Soil 0-30 cm	Soil 0-10 cm	Soil 10-20 cm	Soil 20-30 cm
Forest	187.85 ± 16.12	76.55 ± 7.23	59.81 ± 5.37	50.89 ± 5.25
Non Forest	52.43 ± 9.99	20.68 ± 4.05	16.95 ± 3.89	14.46 ± 3.51

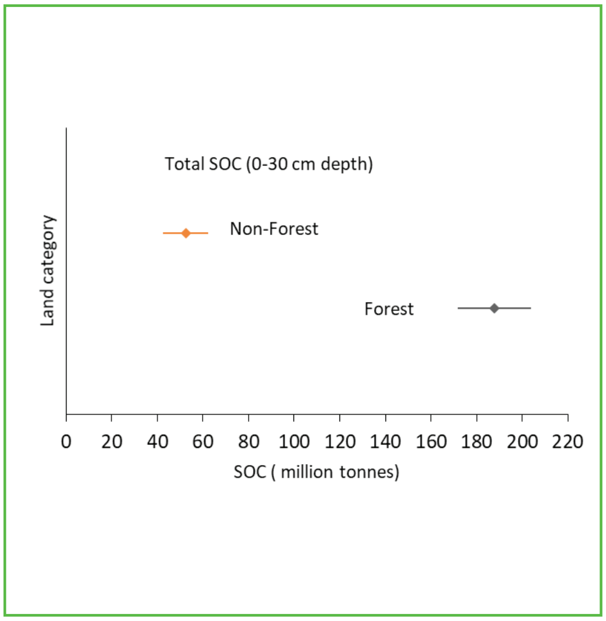


Figure 17: Total SOC (in million tonnes) of soil for a depth of 30 cm soil depth

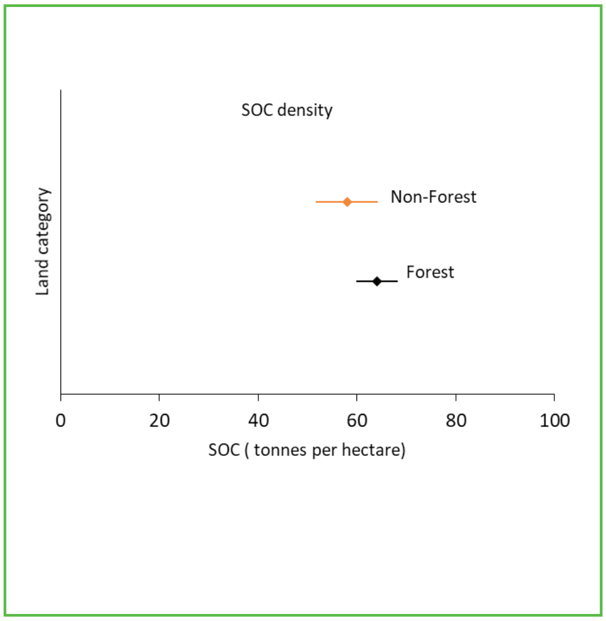


Figure 18: SOC density (tonnes per ha) of soil for a depth of 30cm

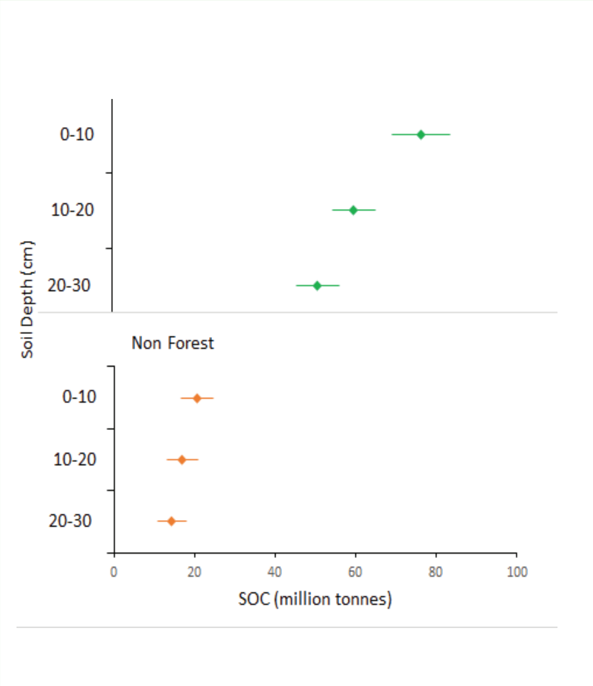


Figure 19: Total SOC by soil depth in forest and non-forest

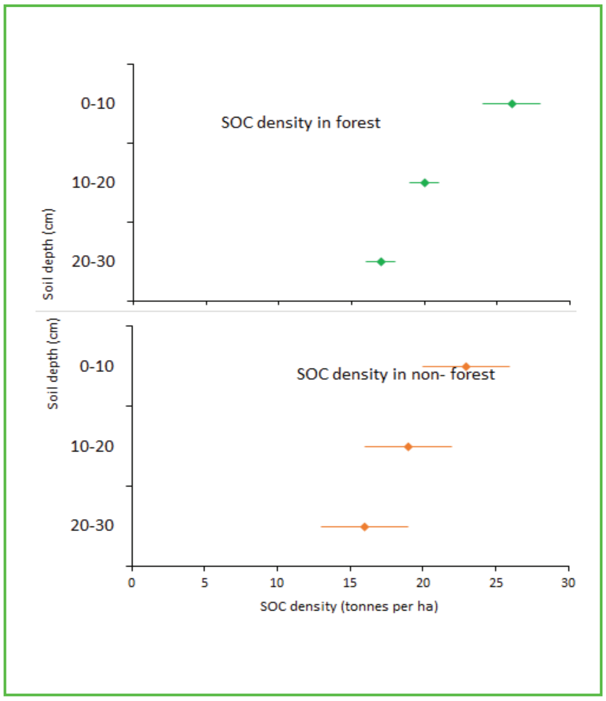


Figure 20: SOC density by soil depth in forest and non-forest

2.1.6 Discussion

The proportional distribution of carbon among the carbon pools indicate their corresponding significance as a carbon store. Seventy four percent (74%) of the carbon is stored in the vegetative carbon pool, while remaining 26 % is stored as SOC. Among the vegetative carbon pool, the living biomass forms a significant carbon store with trees and sapling accounting for nearly 70 % of the total carbon stock. The DOM (Dead Organic Matter) accounts for only 4%.

Our total vegetative carbon density is comparable with carbon densities in Southeast Asian tropical countries (Khun and Sasaki, 2014), and neighboring Indian states of Arunachal Pradesh, Assam, Sikkim and West Bengal (FSI, 2017). The carbon density is mainly contributed to by trees and saplings while the contribution from litter is not very significant.

Diameter is an important tree parameter which dominates the stand structure, forest dynamics and functions (Lutz et al., 2013). It is also the most commonly used tree parameter for modeling tree volume and biomass. In our case, basal area derived from DBH of trees were used for development of biomass models, which are used in estimating the biomass of forest.

The basal area is a good predictor for biomass and carbon since it integrates the effect of both the number and size of trees (Balderas Torres and Lovett, 2012). This explains the relationship between AGB of trees by DBH class with basal area, which shows a similar trend of increase with increase in DBH class up to 60-70 cm and then gradually decreasing with further increase in DBH.

This result indicates that the total biomass (carbon) and biomass density (carbon density) is mostly contributed to by mid-diameter class trees and also indicates that our forests have more number of trees within this diameter category.

When considering the soil carbon pool, it is evident from the vertical distribution of SOC with soil depth that SOC content decreases with increasing depth. Forty one percent (41%) of the total SOC is found within the top layer of 0-10 cm depth, 32% in 10-20 cm and remaining 27% in 20-30cm. This decreasing trend is found in both forest and non-forest, although the magnitude differs. This finding is consistent with other studies on vertical distribution of SOC.

The total SOC is significantly greater in forest than in non-forest mainly because of significant difference in area. NFI Vol I reports 71% of the country as forest and remaining 29% as non-forest (FRMD, 2016). However, there isn't a significant difference in SOC density between forest and non-forest although the SOC density mean value in forest is slightly greater than that of non-forest.

2.2 Forest Biomass and Carbon Estimates by Dzongkhag

2.2.1 Total biomass and carbon estimates by Dzongkhag

Total biomass differs significantly among the different Dzongkhags. It ranges from 7 million tonnes in Gasa Dzongkhag to 96 million tonnes in Trashigang Dzongkhag (Figure 21). The total carbon stock, which is directly related to total biomass, shows the similar trend where, minimum carbon stock is estimated in Gasa Dzongkhag with 3 million tonnes and maximum in Trashigang and Mongar Dzongkhag with 45 million tonnes each (Figure 21 and Table 4)

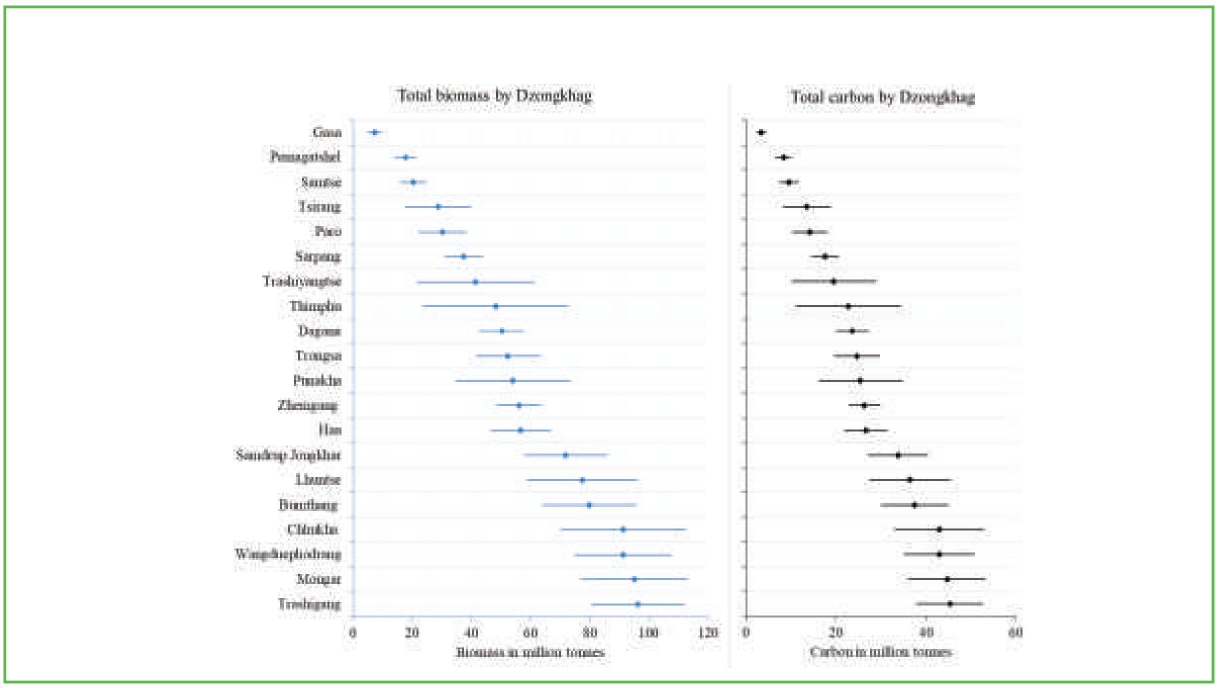


Figure 21: Total biomass and carbon by Dzongkhag

Table 4: Total Biomass and Carbon Stock with confidence interval and margin of error percent

District	Biomass (million tonnes	MoE (%)	Carbon (million tonnes)	MoE (%)
Bumthang	80 ± 16	20	37 ± 7	20
Chhukha	91 ± 21	23	43 ± 10	23
Dagana	50 ± 8	15	24 ± 4	15
Gasa	7 ± 2	31	3 ± 1	31
Haa	57 ± 10	18	27 ± 5	18
Lhuntse	77 ± 19	24	36 ± 9	24
Mongar	95 ± 18	19	45 ± 9	19
Paro	30 ± 8	27	14 ± 4	28
Pemagatshel	18 ± 4	21	8 ± 2	21
Punakha	54 ± 19	36	25 ± 9	36
Samdrup Jongkhar	72 ± 14	20	34 ± 7	20
Samtse	20 ± 5	22	10 ± 2	22
Sarpang	37 ± 6	17	18 ± 3	17
Thimphu	48 ± 25	51	23 ± 12	52
Trashigang	96 ± 16	16	45 ± 7	16
Trashiyangtse	41 ± 20	48	19 ± 9	48
Trongsa	52 ± 11	21	25 ± 5	21
Tsirang	29 ± 11	39	14 ± 5	39
Wangduephodrang	91 ± 16	18	43 ± 8	18
Zhemgang	56 ± 7	13	26 ± 4	13

The distribution of biomass and carbon among the vegetative carbon pool constituents is found to be similar in all Dzongkhags, where the stock is greatest in trees, followed by saplings (Figure 22)

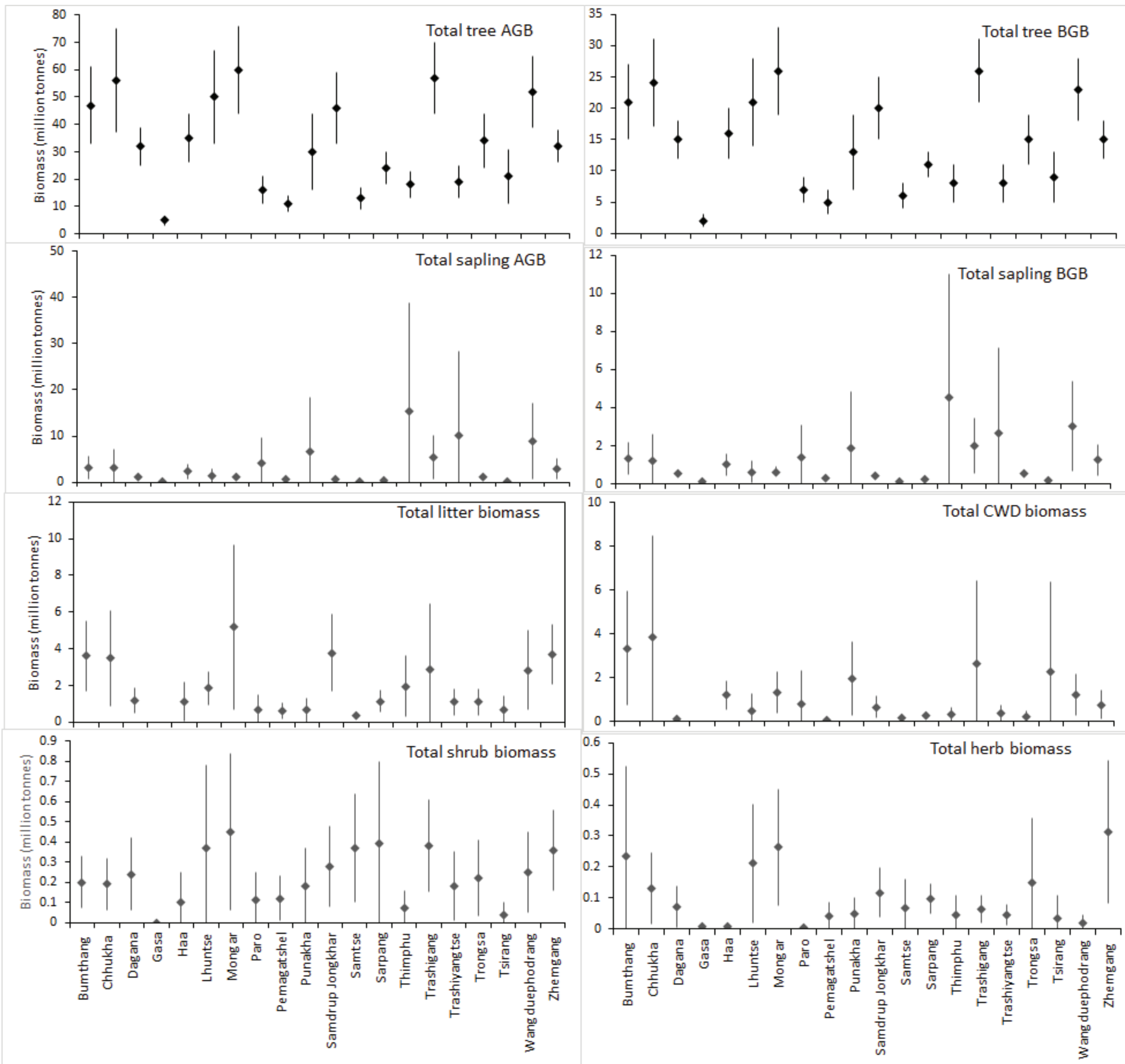


Figure 22: Total biomass estimates of different carbon pools constituent by Dzongkhag

Comparing the total biomass and carbon pool constituent separately, Mongar Dzongkhag has the greatest total above-ground tree biomass (60 million tonnes), closely followed by Trashigang (57 million tonnes), Chhukha (56 million tonnes) and Wangduephodrang (52 million tonnes) while Gasa Dzongkhag has the least (5 million tonnes) (Figure 22).

Sapling above-ground biomass is estimated to be greatest in Thimphu Dzongkhag (15.29 million tonnes) and Gasa has the least total sapling biomass (0.19 million tonnes) (Figure 22).

In terms of tree below-ground biomass, Mongar and Trashigang have the greatest total biomass (26 million tonnes each) while Gasa Dzongkhag has the least. The total sapling below-ground biomass is estimated to be greatest in Thimphu Dzongkhag while Gasa Dzongkhag has the lowest estimated value (Figure 22).

In case of the understory forest biomass, comprising of shrubs and herbs, the total estimated shrub carbon is the highest (0.45 million tonnes) in Mongar while estimates for the Gasa Dzongkhag , although the lowest, is less precise as its confidence interval includes zero. Zhemgang Dzongkhag has the greatest total herb biomass while Paro has the lowest (Figure 22).

The total biomass of CWD and litter is highest in Bumthang (3.18 million tonnes) and Mongar (5.18 million tonnes), respectively.

2.2.2 Biomass and carbon density by Dzongkhag

Comparing the distribution of above-ground biomass density (t/ha) by its constituent (trees, herbs, shrubs and herbs) pools for each of the twenty Dzongkhags, it is observed that the contribution of shrub and herbs to above ground biomass density is comparatively miniscule compared to the other two components, namely the trees and saplings.

Lhuntse Dzongkhag has the greatest above-ground biomass density (480 t /ha), followed by Punakha Dzongkhag (440 t/ha) and Chhukha Dzongkhag (360 t /ha) while it is lowest in Pemagatshel Dzongkhag (110 t/ha) (Figure 23). The above-ground biomass density corresponds with the basal area density reported in NFI volume report I (FRMD, 2016), where basal area is greatest in Lhuntse and lowest in Pemagatshel Dzongkhag.

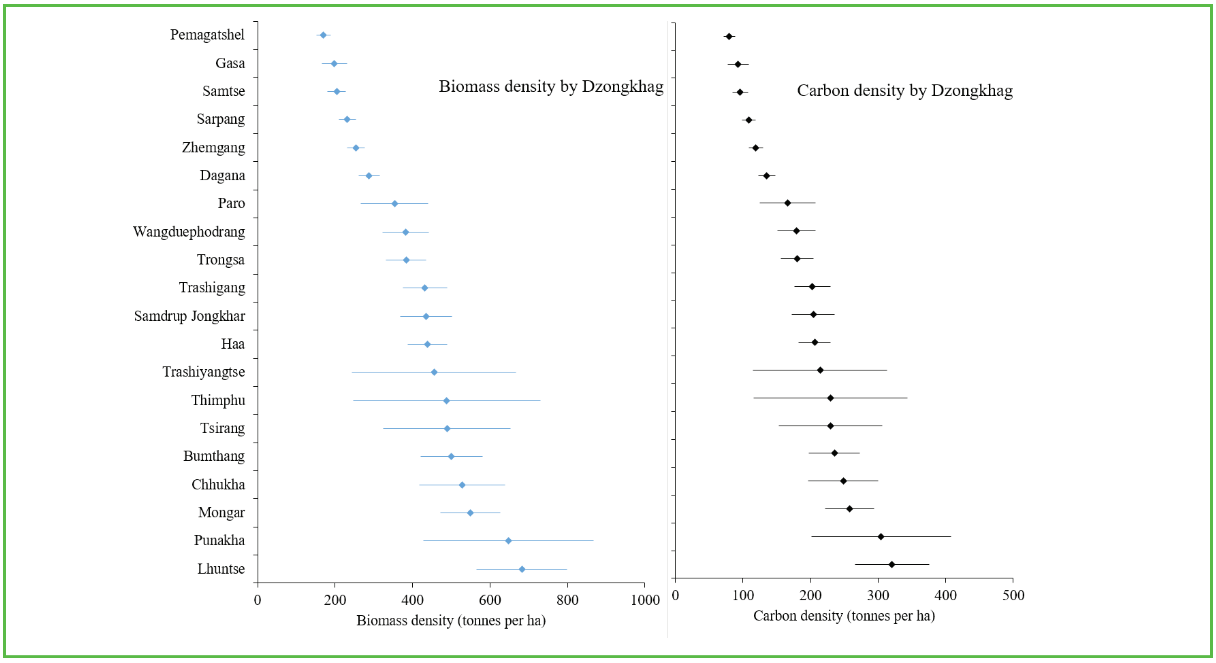


Figure 23: Biomass and carbon density by Dzongkhag

The sapling biomass density is greatest in Thimphu Dzongkhag and lowest in Sarpang. The shrub biomass density ranges between 0.28 t/ha to 3.25 tonnes per ha among the Dzongkhags (Figure 24)

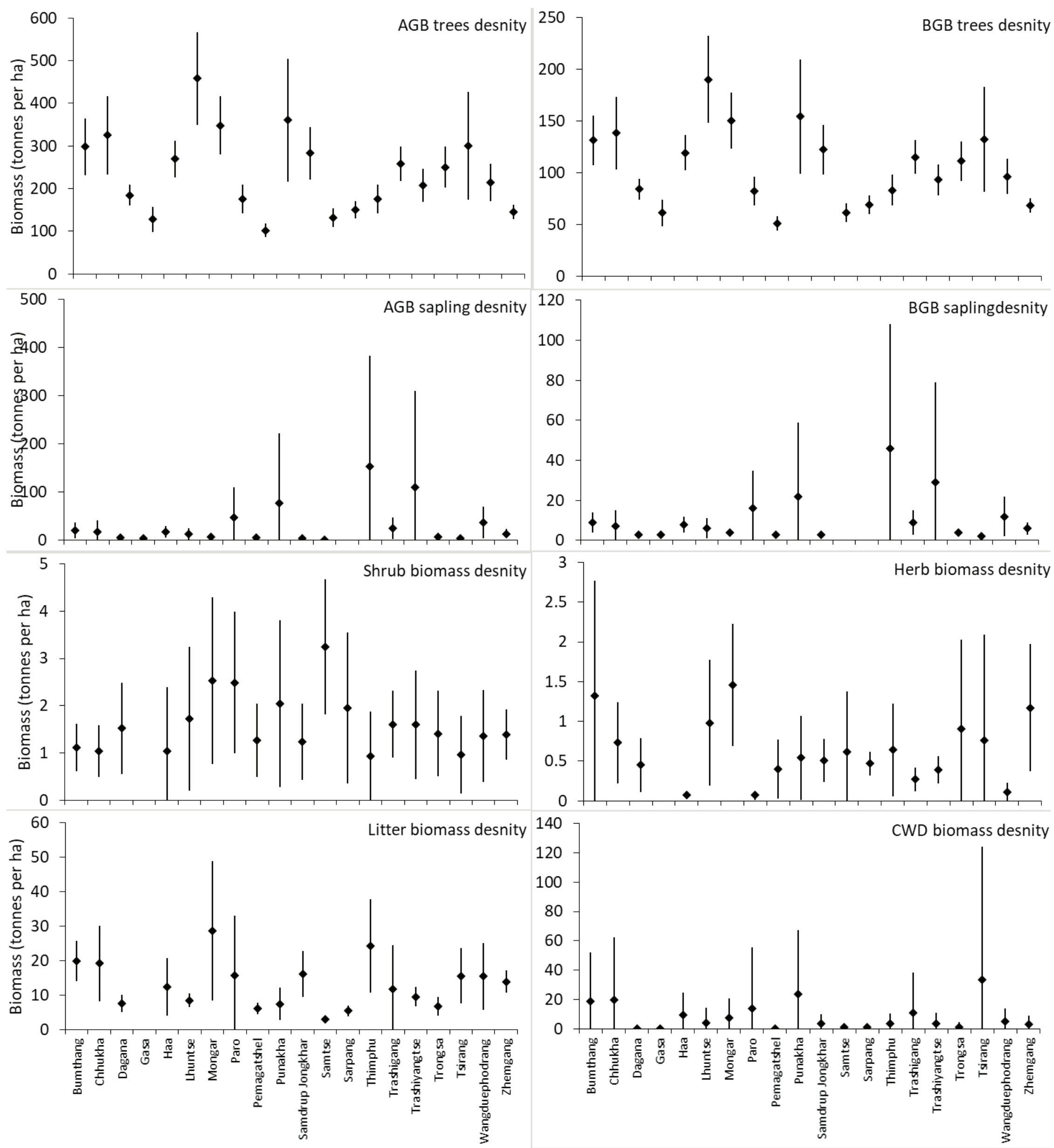


Figure 24: Biomass density of carbon pool constituents by Dzongkhag

Herb biomass density is highest in Mongar at 0.62 t/ha and lowest in Haa at 0.07 t/ha. Biomass density in DOM is equally variable with no evident correlation between the two. CWD biomass density is highest in Tsirang and while litter is highest in Mongar.

2.2.3 Soil organic carbon estimates by Dzongkhag

The SOC content varies widely among the different Dzongkhags and ranges from 2 million tonnes in Paro to 16 million tonnes in Trashigang(Figure 25). Gasa Dzongkhag is not reported due to lack of adequate sampling units for SOC analysis.
However, the SOC density (t/ha) is found to be greatest in Tsirang with 197 t/ha, followed by Trashiyangtse with 98 t/ha and least in Pemagatshel with 45 t/ha. All Dzongkhags, except Tsirang, have SOC densities less than 100 t/ha.

The SOC content by soil depth within individual Dzongkhag also decreases with increasing depth (Figure 27) as was observed for the national estimate.

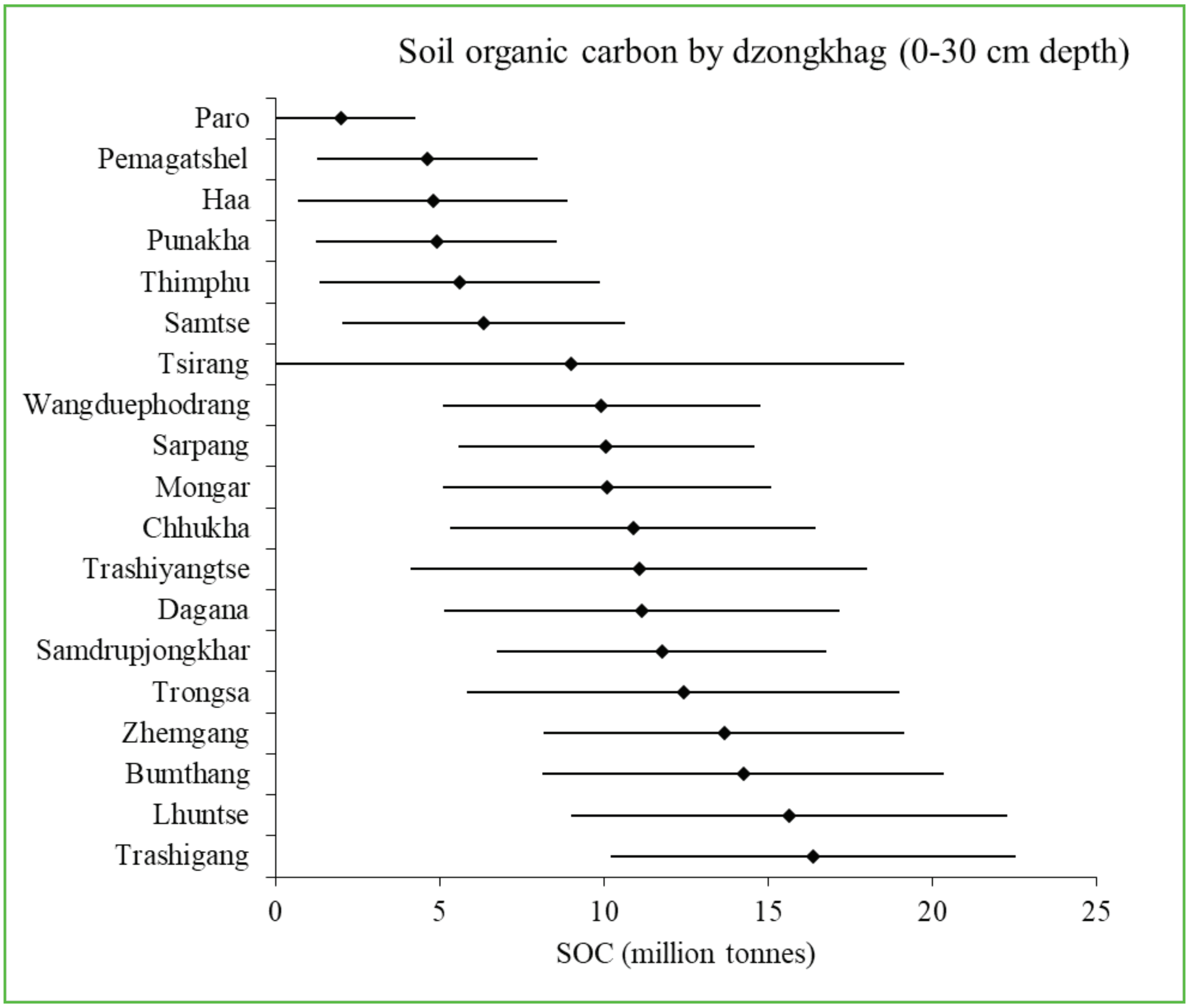


Figure 25: Total Soil Organic Carbon estimates by Dzongkhag

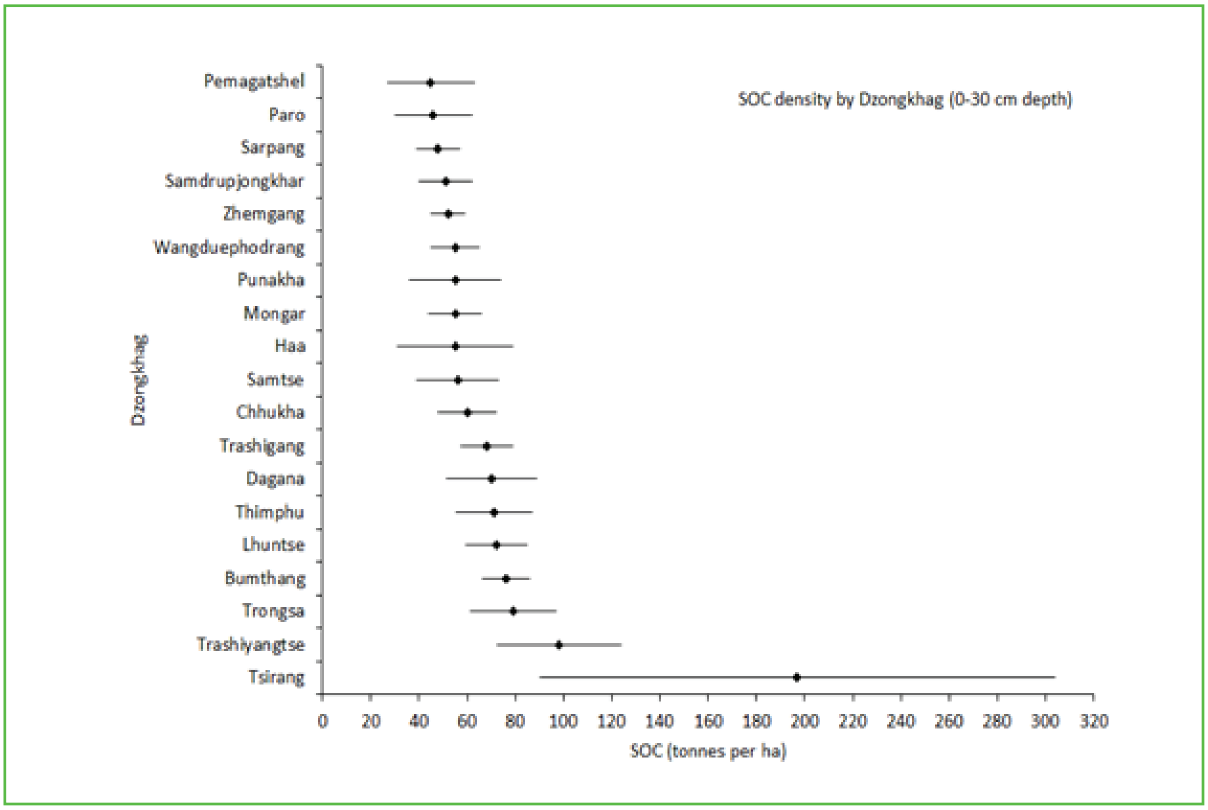


Figure 26: SOC density of soil for a depth of 30cm

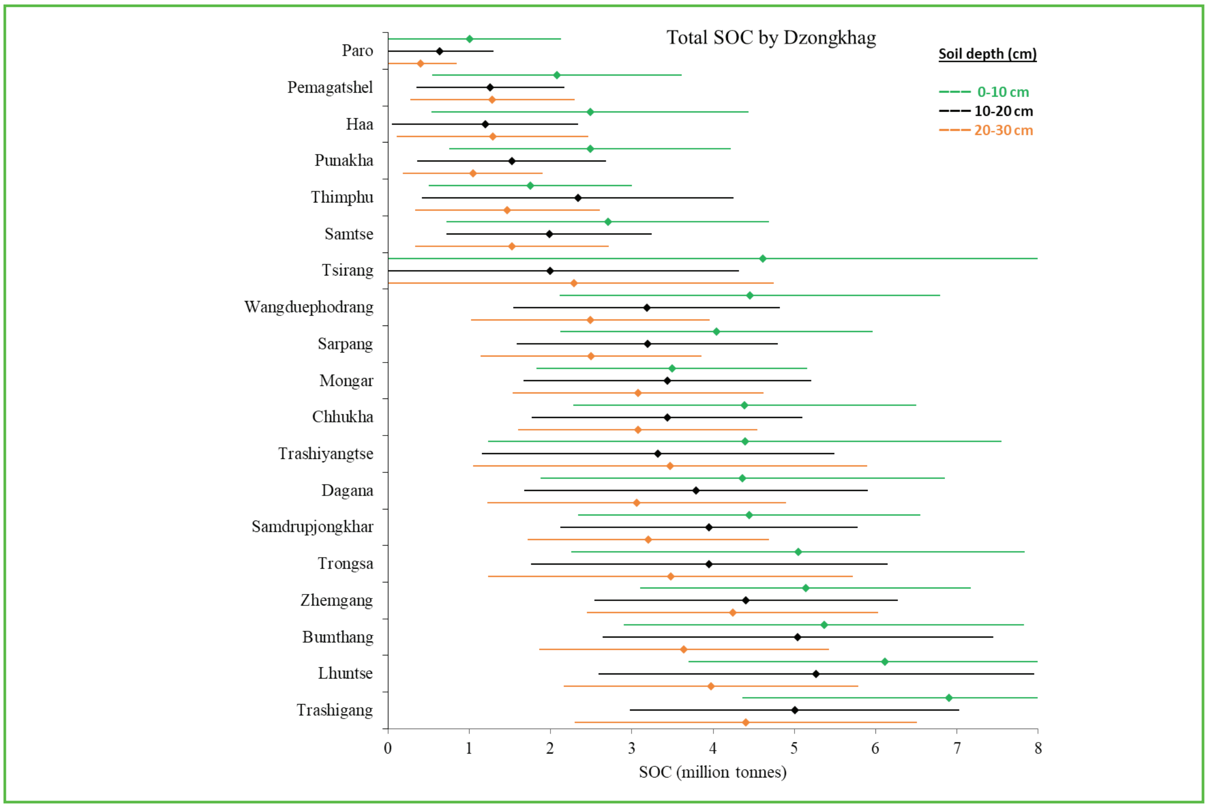


Figure 27: Total SOC by Dzongkhag at different soil depths

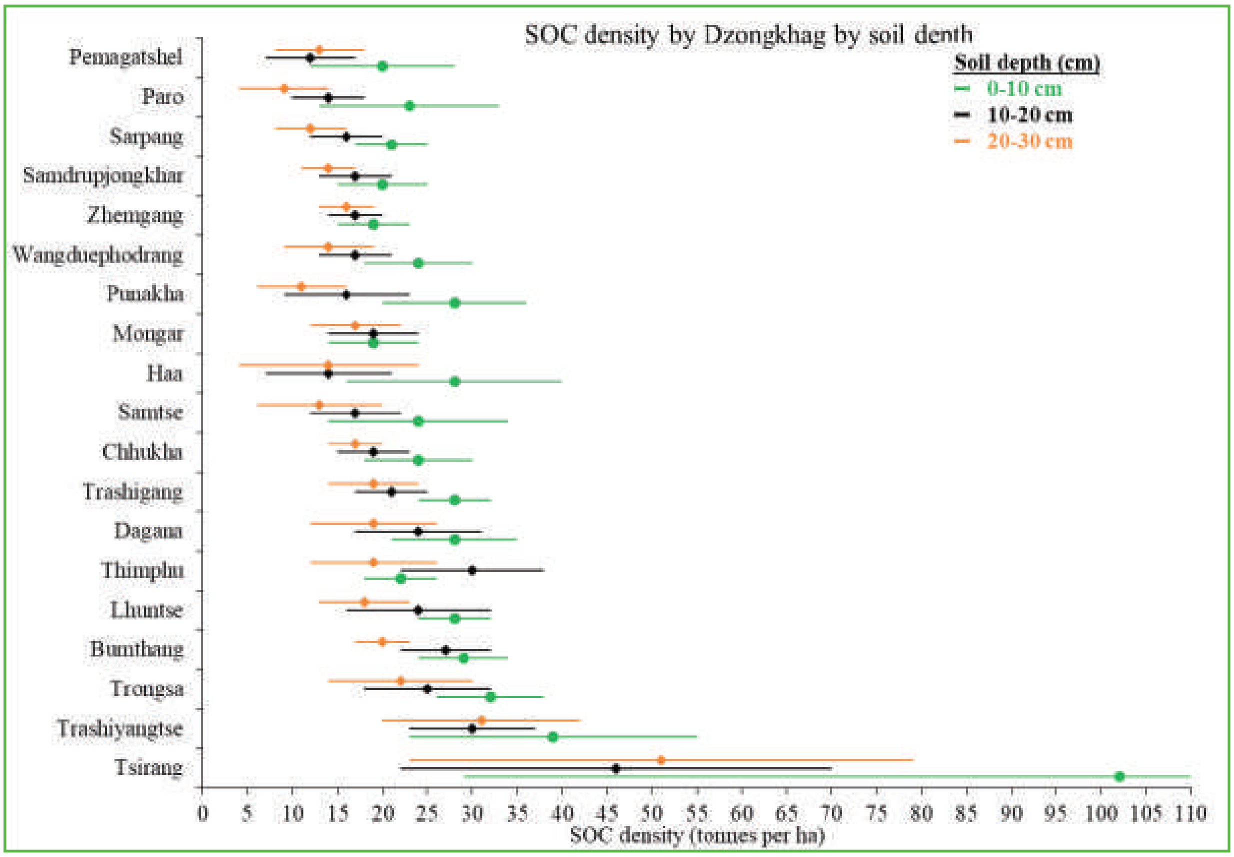


Figure 28: SOC density at different soil depth

2.2.4 Discussion

The biomass and carbon stock varies greatly among the Dzongkhags and cannot not be explained by any particular trend, given the varied combination of diverse environmental factors existing within the Dzongkhags, which greatly influence the biomass and carbon storage. However, based on the above-ground biomass density, it may be inferred that AGB density is affected more by the basal area density, since it corresponds with the basal area density reported in NFI volume report I (FRMD, 2016), where basal area estimates are greatest in Lhuntse and the lowest in Pemagatshel Dzongkhag.

Observations within individual Dzongkhag show a similar distribution of carbon among the carbon pools as were observed at national level. Trees and saplings are found to be the greatest store of vegetative carbon pool, followed by soil, then DOM and the lowest amounts in the herbs and shrubs pools. Similarly, the diminishing SOC with depth can also be observed within individual Dzongkhag.

2.3 Forest Biomass and Carbon estimates by Forest Type

2.3.1 The biomass and carbon estimate by forest type

The forest in Bhutan can be broadly categorized into broadleaf and conifer forest purely on the basis of predominant vegetation composition. Comparing the biomass and carbon within this broad category of forest, the total biomass is found to be greater in broadleaf forest than in conifer forest (Figure 29), the total biomass in broadleaf forest is estimated to be 726 ± 43 million tonnes compared to 369 ± 45 million tonnes is conifer forest (Table 5). Conversely, the biomass density is greater in conifer forest than in broadleaf forest. Conifer forest has 486 ±50 t/ha while broadleaf has 380 ± 20 t/ha (Table 5 and Figure 30).

The contribution of carbon pool constituents to total biomass and carbon are same in both broadleaf and conifer forest, where trees and saplings forming the major portion of biomass/carbon stock while contribution of litters, CWD, shrubs and herbs are comparatively low. (Table 5 and Figure 31 to Figure 34)

Table 5: Biomass and carbon by its constituent pool in broadleaf and conifer forest

	Biomass (million tonnes)		Carbon (million tonnes)	
Carbon Pools	Broadleaf forest	Conifer forest	Broadleaf forest	Conifer forest
Tree AGB	449 ± 34	203 ± 32	211 ± 16	95 ± 15
BGB Tree	199 ± 14	89 ± 13	94 ± 7	42 ± 6
Sapling AGB	26 ± 20	42 ± 27	12 ± 9	20 ± 13
Litter	25 ± 5	13 ± 5	12 ± 3	6 ± 2
CWD	12 ± 5	6 ± 5	6 ± 2	3 ± 2
Sapling BGB	10 ± 5	14 ± 7	5 ± 2	6 ± 3
Shrub	3.66 ± 0.75	0.86 ± 0.27	1.72 ± 0.35	0.4 ± 0.13
Herb	1.5 ± 0.38	0.54 ± 0.3	0.71 ± 0.18	0.25 ± 0.14
Total	726 ± 43	369 ± 45	341 ± 20	173 ± 21

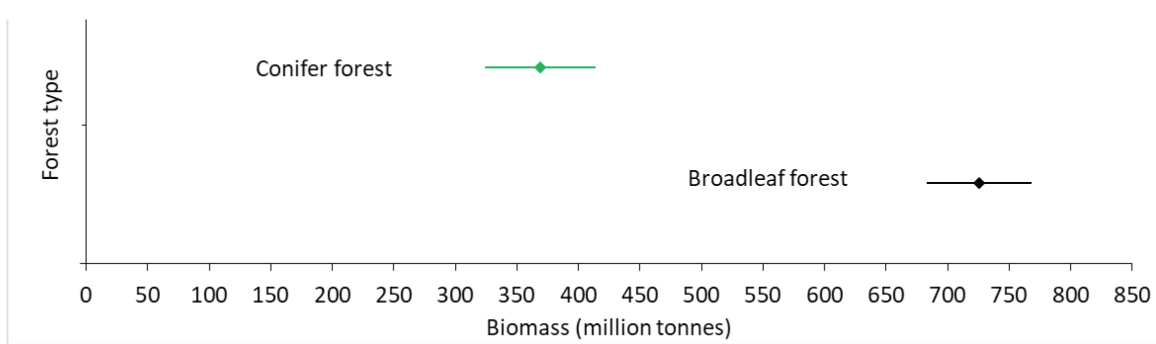


Figure 29: Total biomass in broadleaf and conifer forest

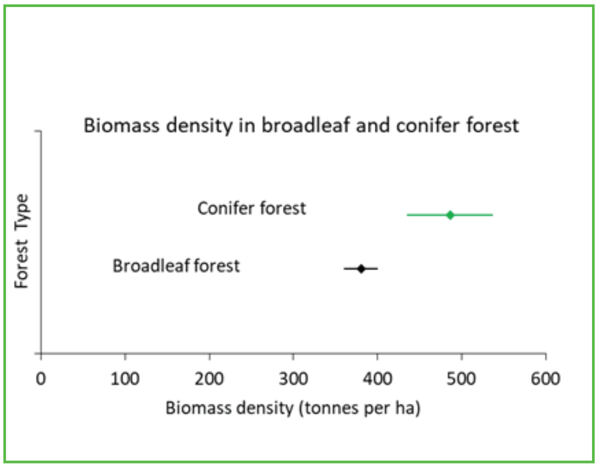


Figure 30: Biomass density of broadleaf and conifer forest

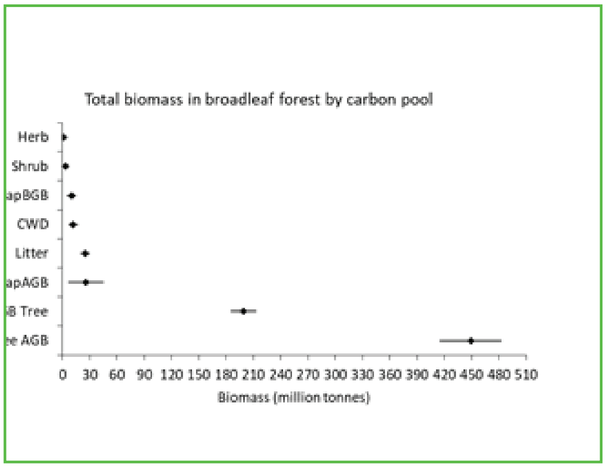


Figure 31: Total biomass by carbon pool constituents

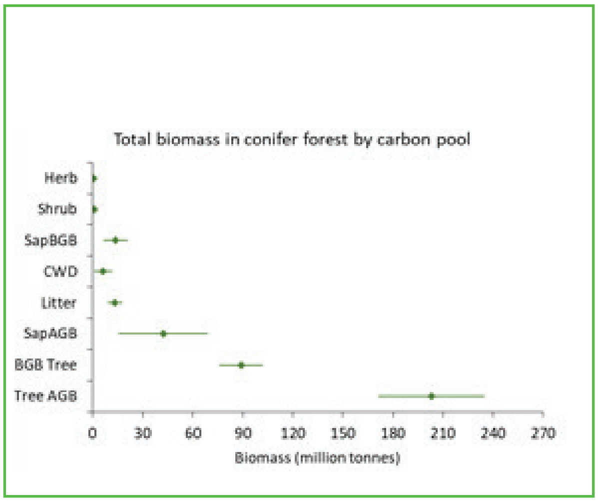


Figure 32: Total biomass by carbon pool constituents in conifer forest

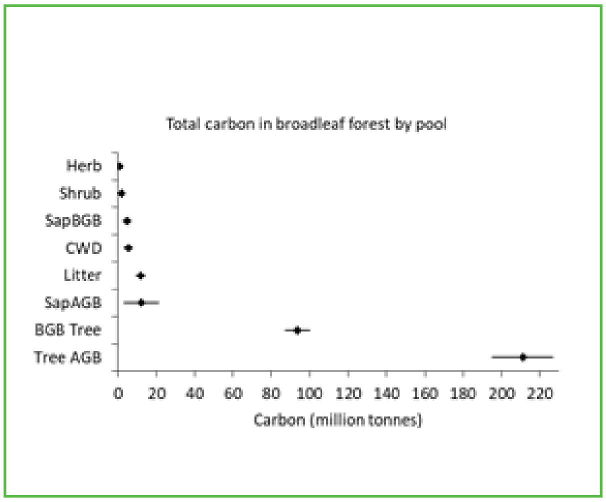


Figure 33: Total carbon by carbon pool constituent in broadleaf forest

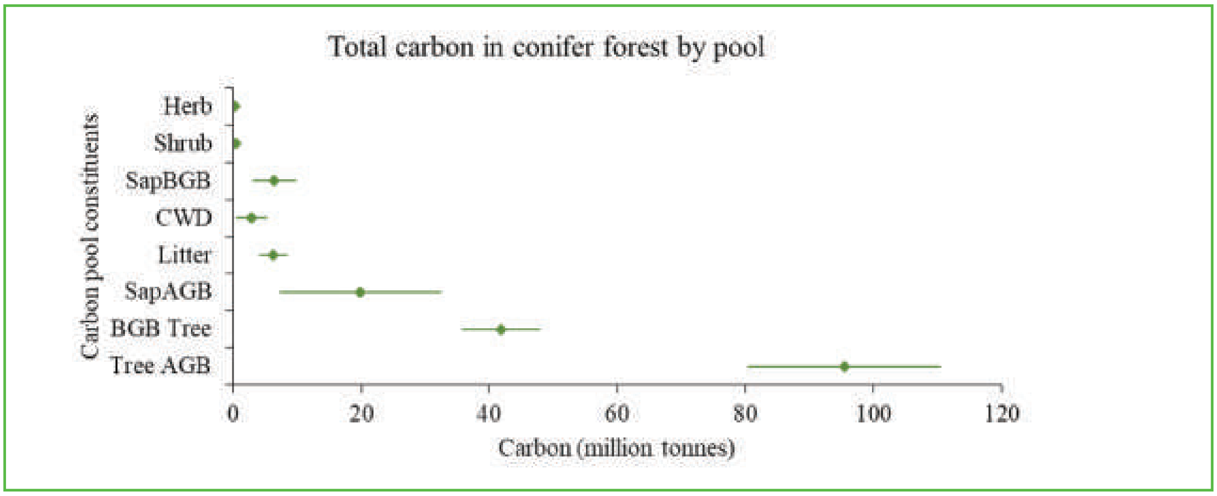


Figure 34: Total carbon by carbon pool constituent in conifer forest

Assessing the biomass and carbon within the forest when segregated into 11 forest types, the total biomass is estimated to be greatest in the Cool Broad-leaved Forest (500 ± 41 million tonnes) and Warm Broad-leaved Forest (190 ± 17 million tonnes) and least in Juniper-Rhododendron scrub (13 ± 4 million tonnes). The proportion of total estimates correspond to proportion forest area reported under different forest types in NFI report I (FRMD, 2016) and Land Use Land Cover Atlas (FRMD, 2017). Forest type with larger area has greater biomass and carbon. The biomass and carbon density, however, doesn't follow this trend.

A study in India by Salunkhe et al. (2018) has reported the similar situation where total biomass is accounted by area under particular forest type while biomass density does not necessarily have the similar relation.

Table 6: Total biomass and carbon estimates by forest type

Forest Type	Biomass (million tonnes)	Margin of Error (million tonnes)	Carbon (million tonnes)	MoE
Cool Broad-leaved Forest	500	41	235	19
Warm Broad-leaved Forests	190	17	89	8
Fir Forest	153	19	72	9
Blue Pine Forest	78	32	36	15
Hemlock Forest	48	11	23	5
Subtropical forest	43	5	20	2
Chir pine Forest	38	17	18	8
Spruce Forest	20	8	9	4
Evergreen Oak Forest	17	6	8	3
Juniper Rhododendron Scrub	13	4	6	2
Dry Alpine Scrub	0.12	0.13	0.05	0.06

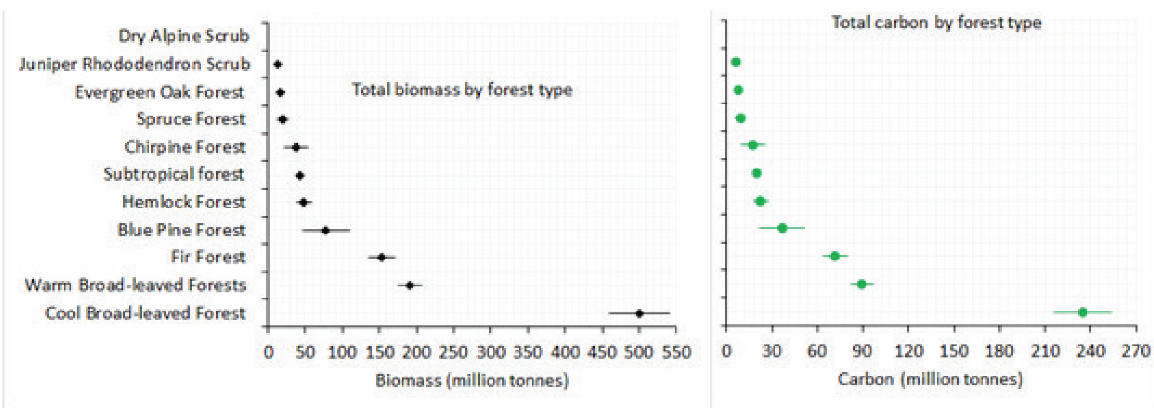


Figure 35: Total biomass and forest carbon estimates by forest type

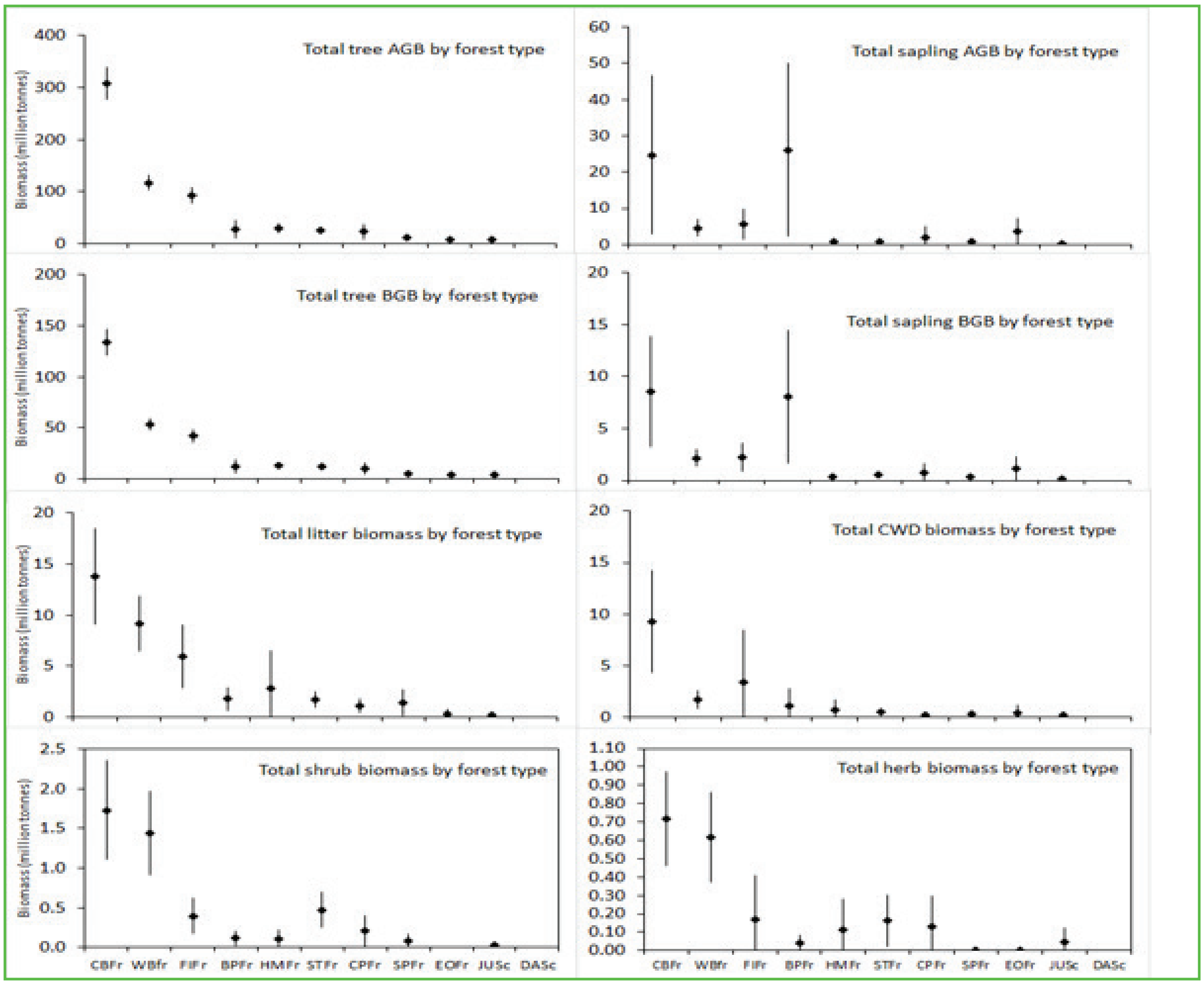


Figure 36: Total biomass estimates of carbon pool constituents by forest type

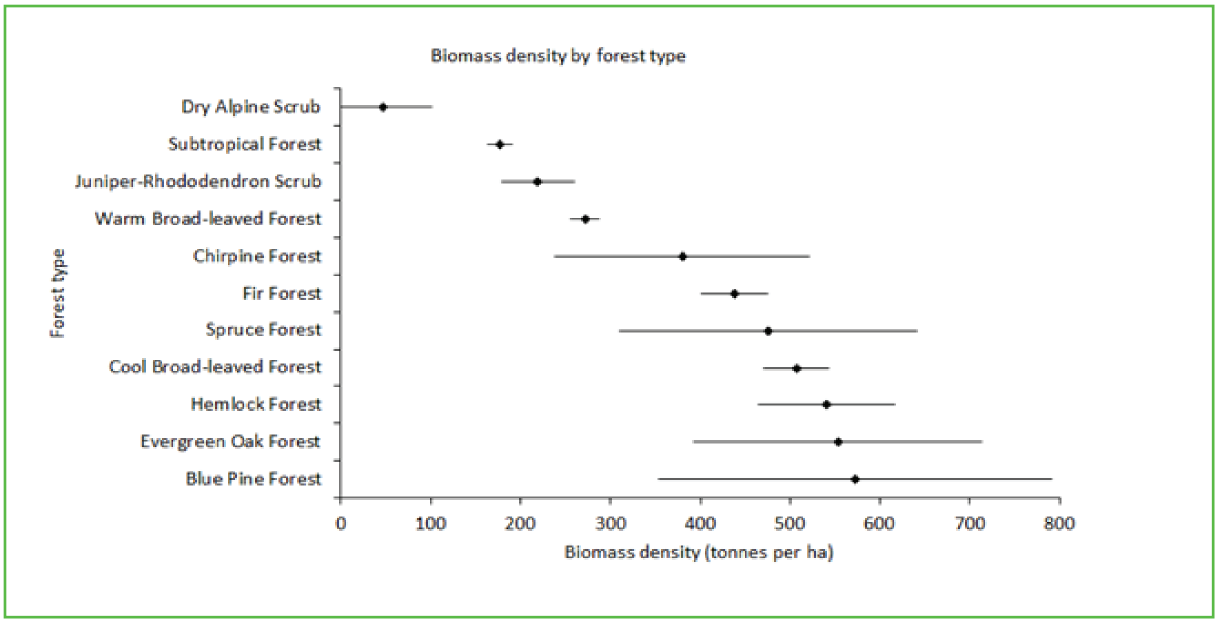


Figure 37: Biomass density by forest type

Density wise, the above-ground and below-ground tree biomass density varies widely among the forest types (Figure 38). The Hemlock forest has greatest biomass density with 492 t/ha, closely followed by 447 t/ha in Cool Broad-leaved Forest (t/ha), which is consistent with studies carried out in other countries, such as Australia (Keith et al., 2009) and India (Salunkhe et al., 2018), in similar forest types.

The sapling above-ground and below-ground also varies among the different forest types. Blue pine forest has the greatest total sapling above-ground and below-ground biomass per hectare while dry alpine scrub forest has the least. (Figure 38)

The dead wood biomass (coarse woody debris) of the eleven forest types of Bhutan (DoFPS, 2011) ranged from 1 to 12 t/ha and mean CWD biomass across the forest types 6 t/ha. The CWD biomass is estimated to be greatest in evergreen oak forest, followed by blue pine forest, fir forest, cool broad-leaved forest and hemlock forest and lowest in chir pine forest. (Figure 38)

The litter biomass ranged from 3 to 25 t/ha and mean litter biomass across the forest types is 6 t/ha. The hemlock forest has the greatest estimated litter biomass closely followed by Evergreen Oak Forest, while juniper rhododendron forests and cool broad-leaved forest has the least litter biomass per ha. Although the CWD estimates has high uncertainties ,the estimates for both CWD and litter are within the range prescribed by IPCC,2006 for greenhouse gas inventory and independent study conducted in temperate forests of Kashmir Himalayas, India (Dar and Sundarapandian, 2015).

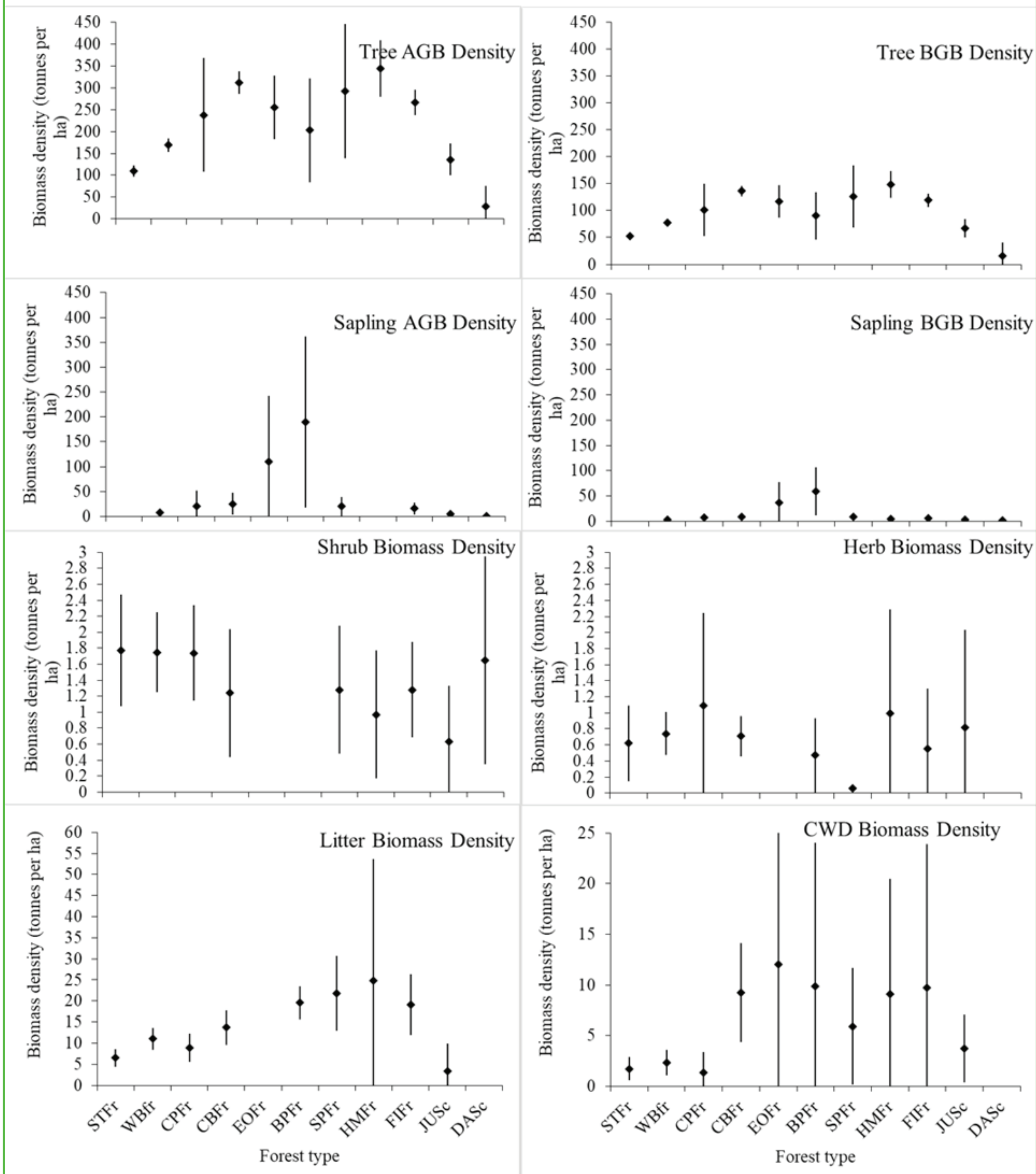


Figure 38: Biomass density of carbon pool constituents by forest type

2.3.2 Soil organic carbon by forest type

Soil organic carbon has very strong correlation with vegetation type. Studies in the past have reported different SOC content under different forest types (Panwar and Gupta, 2013; Dorji et al., 2014; Ali et al., 2017; NSSC, 2017) and it has been inferred to have been influenced mostly by precipitation and temperature (Simon et al., 2018).

The total SOC is greater in broadleaf forest than in conifer forest. Broadleaf forest contains 134 ± 16 million tonnes of SOC while conifer forest has 51 ± 11 million tonnes of carbon (Figure 39). The density or per hectare estimates are, however, very slightly greater in conifer forest (66 ± 6 t/ha) compared to broadleaf forest (64 ±6 t/ha) (Figure 40). The decreasing SOC content by depth is visible for both broadleaf and conifer forest (Figure 41 and Figure 42).

Comparing the total SOC amongst 11 forest types, it decreases in the order of cool broad-leaved forest, warm broadleaf forest, sub-tropical forest, fir forest, hemlock forest, blue pine forest, chir pine forest, juniper-rhododendron scrub forest, spruce forest and evergreen oak forest (Figure 43). Cool broadleaf forest has 74 million tonnes of SOC while evergreen oak forest has only 2 million tonnes of SOC.

SOC density is greatest in blue pine forest (87 ± 81 t/ha) and the lowest in sub-tropical forest (36 ± 5 t/ha). Cool broad-leaved forest, which has the greatest total SOC, has SOC density of 64 ± 4 t/ha and ranks fourth greatest SOC density of the forest types in Bhutan (Figure 44).

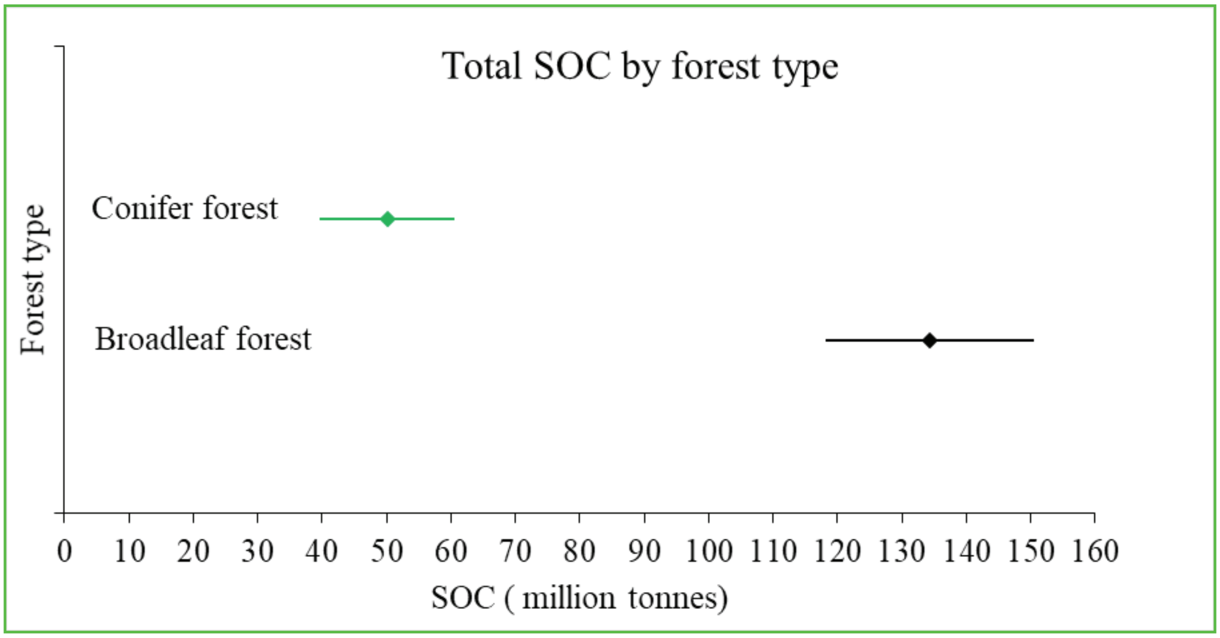


Figure 39: Total SOC for a depth of 30cm in broadleaf and conifer forest

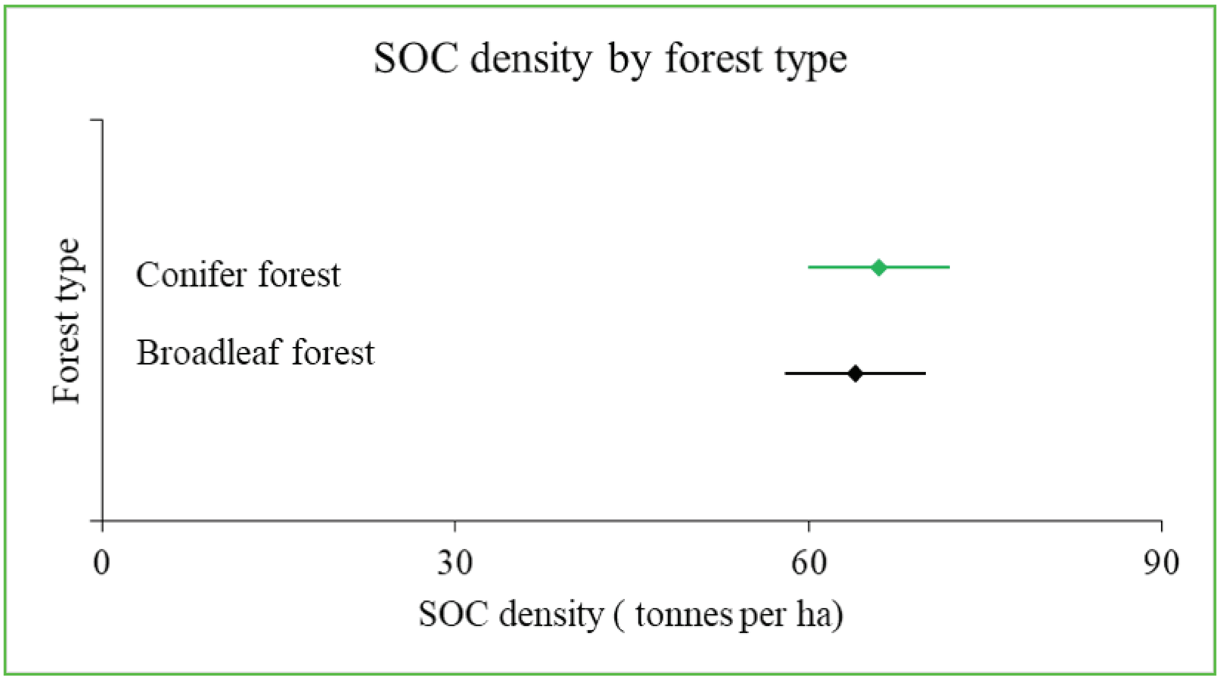


Figure 40: SOC density for a depth of 30 cm in broadleaf and conifer forest

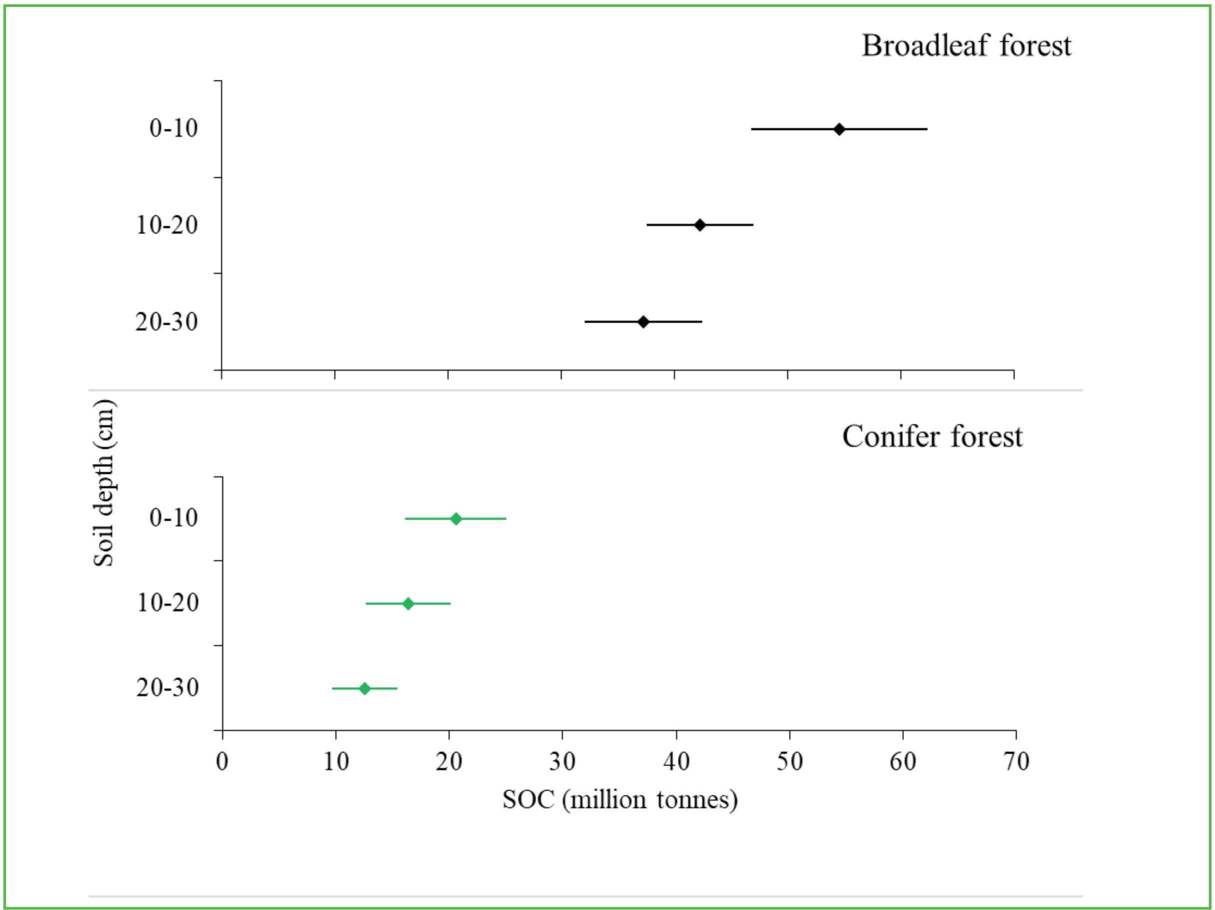


Figure 41 : Comparing total SOC of broadleaf forest and conifer forest at different soil depth

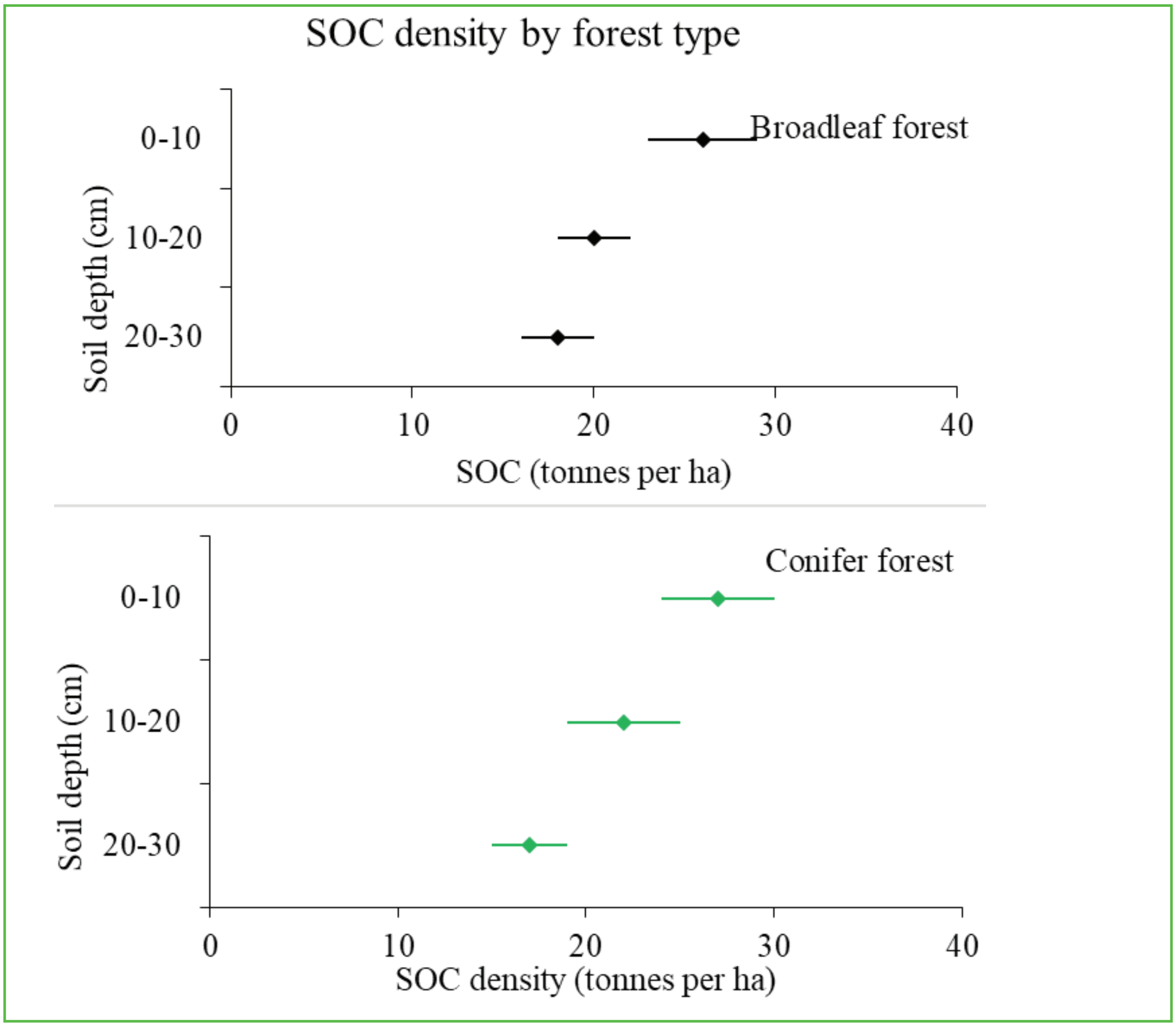


Figure 42: Comparing SOC density of broadleaf forest and conifer forest at different soil depth

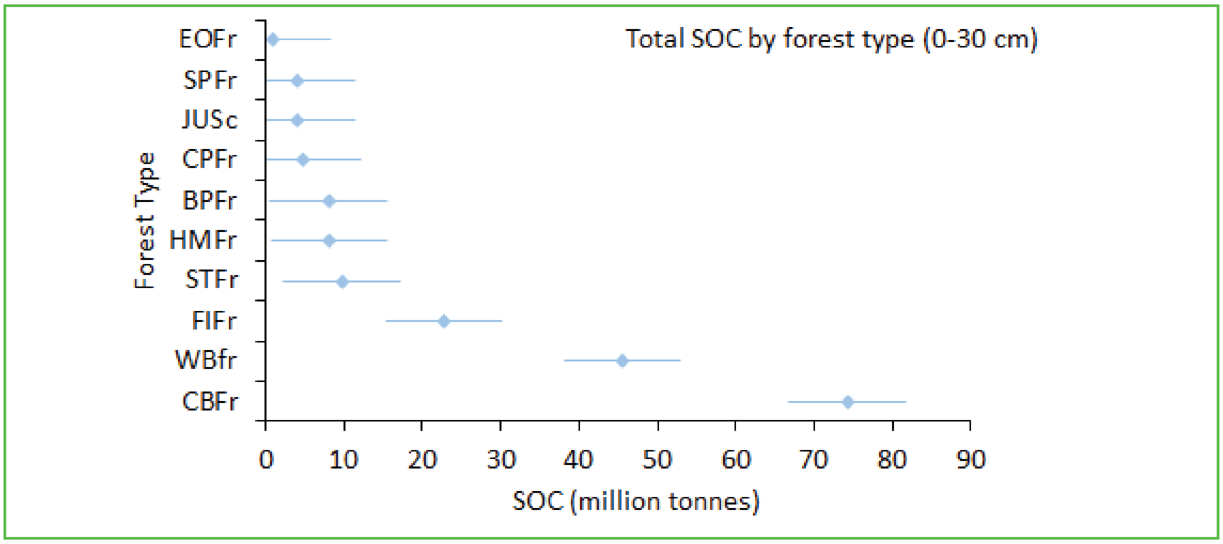


Figure 43: Total SOC within a depth of 30cm for different forest types

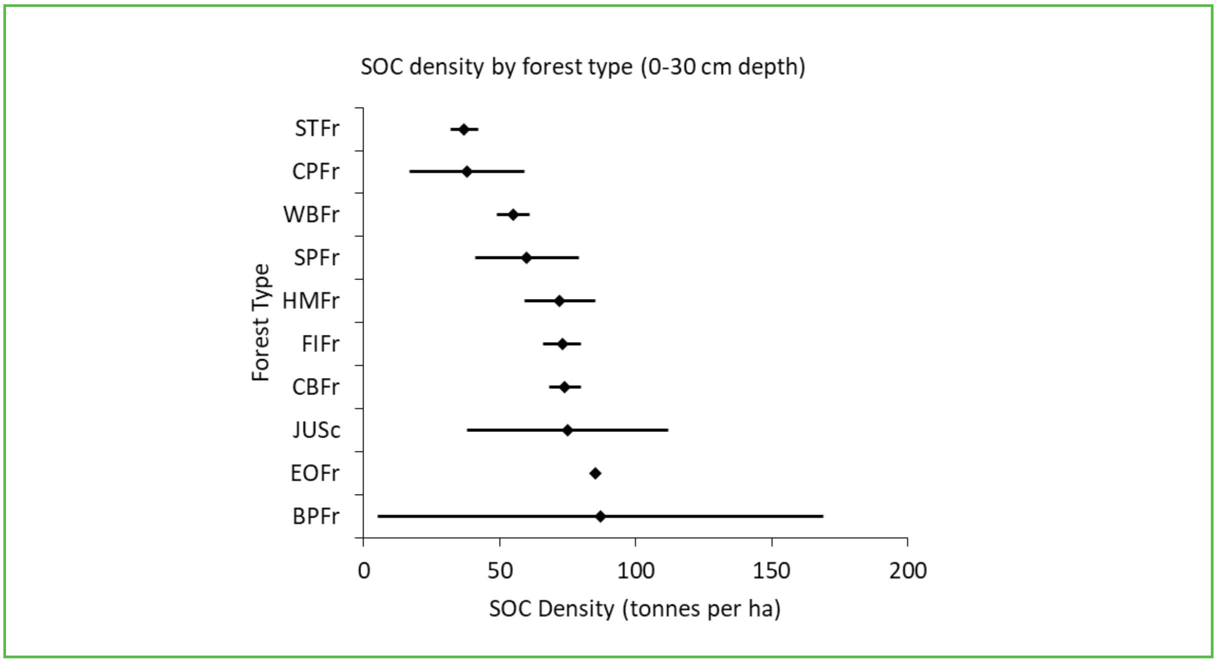


Figure 44: SOC density for a depth of 30cm (tonnes per hectare) by forest type

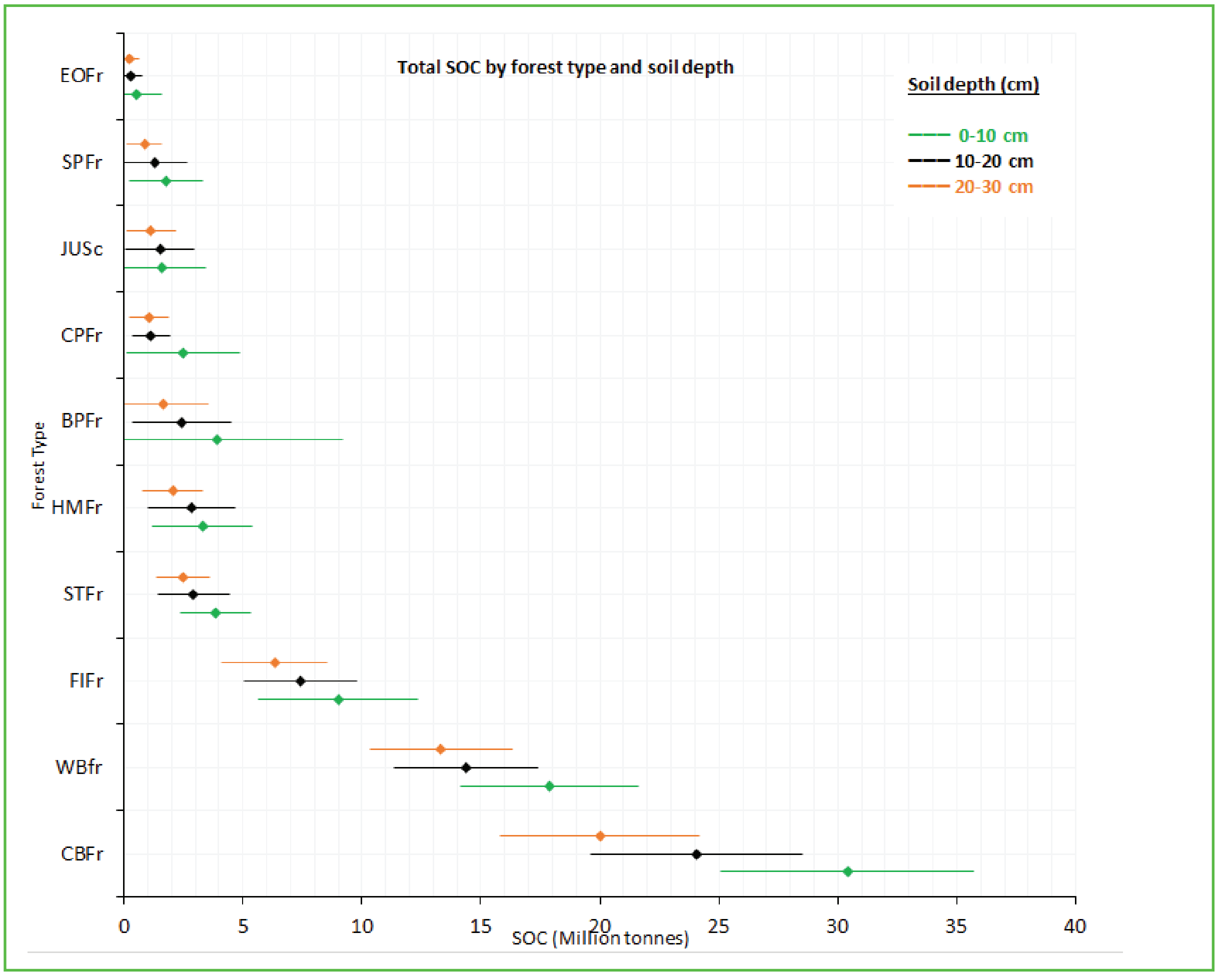


Figure 45: Depth wise total SOC by forest type

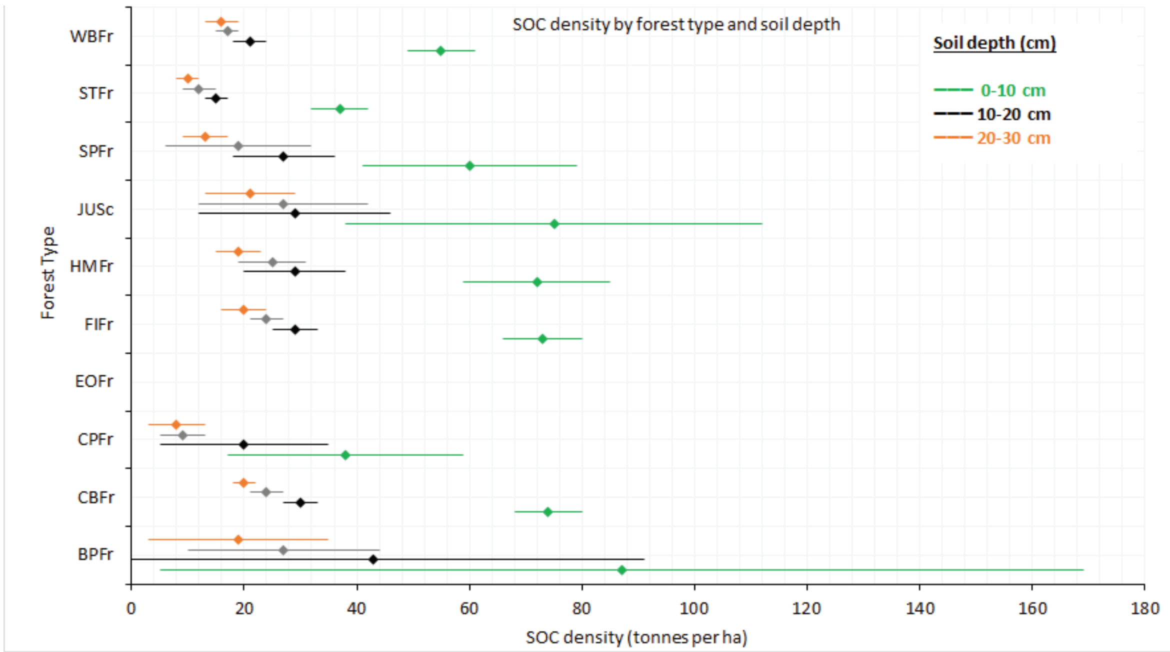


Figure 46: Depth wise SOC density by forest type

2.3.3 Discussion

Globally, carbon sequestration capacity differs by forest type (Keith et al., 2009; Zhu et al., 2010) (Zhu et al., 2010; IPCC, 2006; Keith et al., 2009) due to differences in species composition (Gairola et al., 2011a; Dar and Sundarapandian, 2015), climatic and geographic variation (Salunkhe et al., 2018). Studies in Australia (Keith et al., 2009), India (Gairola et al., 2011a; Dar and Sundarapandian, 2015; Salunkhe et al., 2018) and Nepal (Pradhan et al., 2012; Karki et al., 2016) reported variation in biomass in different forest types.

Comparing the biomass density for two broad categories of forest as conifer forest and broadleaf forest, it is observed that while the density (per hectare) estimates are higher for conifer forest than broadleaf forest; the total biomass stock is higher in broadleaf forest. This could very well be explained by the fact that conifer forest has higher tree count and basal area per hectare than broadleaf forest. However, the total stock is determined by the area and therefore the broadleaf forest, which consists of 65 % of the total forest cover (FRMD, 2017) has higher total biomass and carbon stock than conifer forest. Similarly, the total SOC content is greater in broadleaf forest than in conifer forest. SOC density in broadleaf is 64 t/ha while that of conifer is 66 t/ha.

2.4 Forest Biomass and Carbon estimates by Elevation

2.4.1 Biomass and carbon by elevation

The total biomass and carbon stock is greatest in 2000-3000 m elevation range with 497 ±45 million tonnes of biomass and least at elevation greater than 4000 m with 2 ± 1 million tonnes of biomass (Refer Table 7 for corresponding carbon estimates). The tree biomass, sapling biomass and biomass from DOM is greatest at 2000-3000 m while biomass in herbs and shrubs are greatest in 1000-2000 m elevation (Figure 49). The carbon pool constituents of significant contribution to overall carbon stock is greatest at 2000-3000 m.

Biomass density is also greatest at 2000-3000 m elevation with 540 ± 43 t/ha and least at elevation greater than 4000 m with only 144 ± 45 t/ha. Comparing the biomass density by carbon pool constituents, the AGB in trees gradually increases from 196 tonnes of biomass per hectare at less than 1000 m to 313 tonnes of biomass at 2000-3000 m. At 3000-4000 m, the biomass density decreases to 279 t/ha and then to 93 t/ha above 4000 m. Similar trend is observed with saplings, which peaks at 2000-3000 m elevation range. (Figure 52).

In the case of shrubs and herbs pools, the biomass density is greatest at 1000-2000 m with an estimate of 1.8 t/ha and 0.74 t/ha, respectively. The lowest density for both are found at the 3000-4000 m at 1.11 t/ha and 0.43 tonnes per hectare. Due to inaccessibility, very limited number of sample plots could be established for forest carbon understory from areas falling above 4000 m and thereby resulting in inability to generate estimates for these areas (Figure 52).

Dead organic matter, namely coarse woody debris (CWD) and litter are observed to increase in biomass density with elevation. However, given the lack of adequate data and sample from 4000 m and above , it is not evident, whether the biomass in DOM would increase or decrease at that high elevation range (Figure 52).

Table 7: Total biomass and carbon estimates by elevation range

	Elevation (m)				
	<1000	1000-2000	2000-3000	3000-4000	>=4000
Total Biomass (million tonnes)	74 ± 8	272 ± 26	497 ± 45	262 ± 25	3 ± 1
Total Carbon (million tonnes)	35 ± 4	128 ± 12	234 ± 21	123 ± 12	1 ± 1

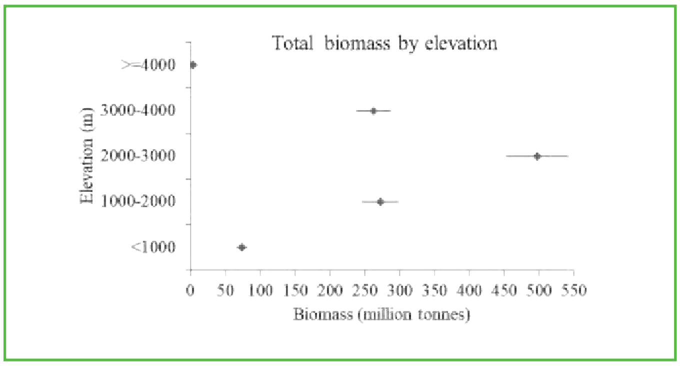


Figure 47: Total biomass estimates by elevation range

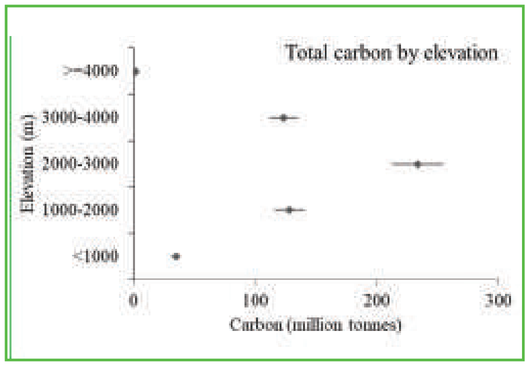


Figure 48: Total carbon estimates by elevation

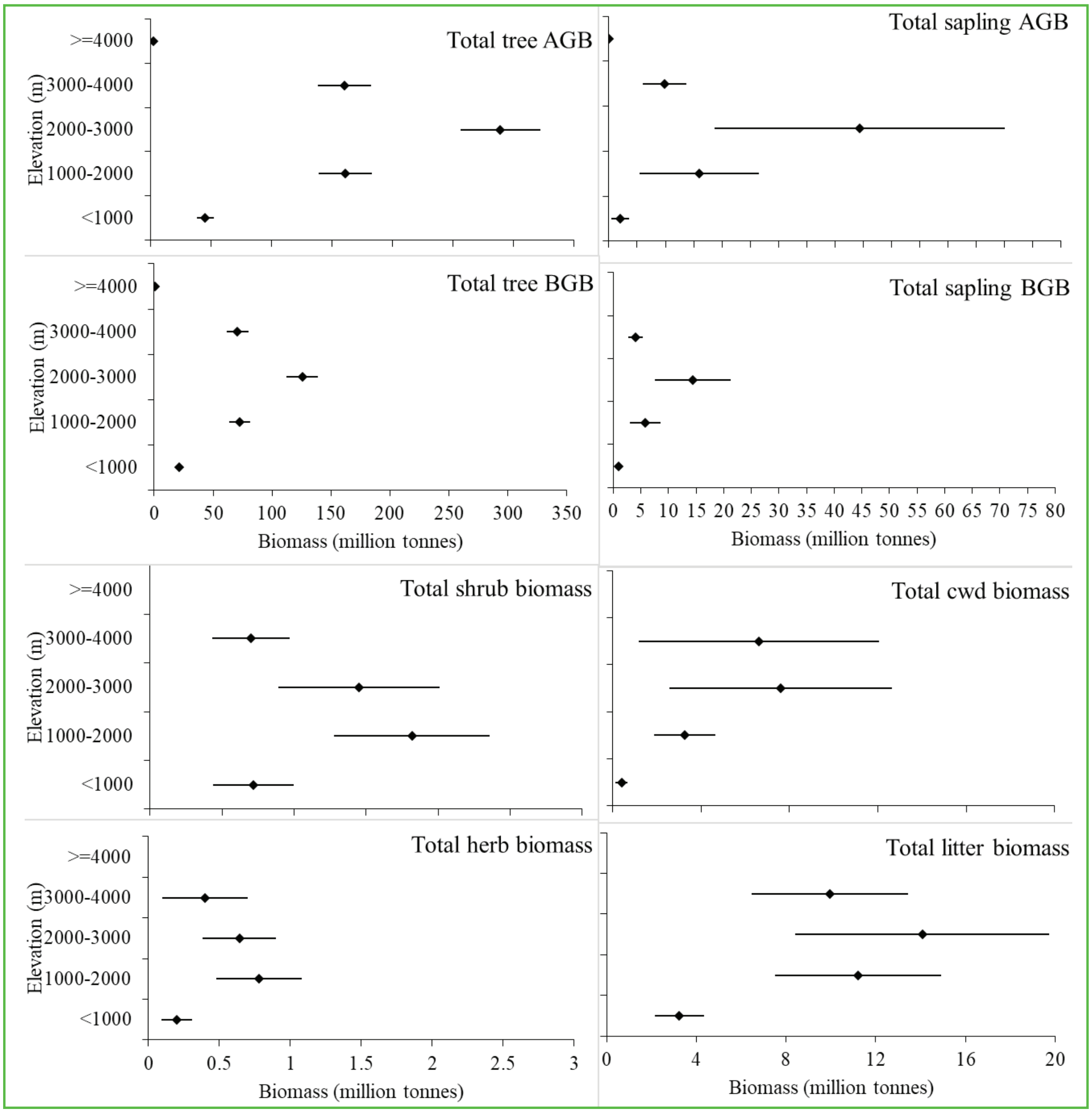


Figure 49: Total biomass estimates of the carbon pool constituents by elevation

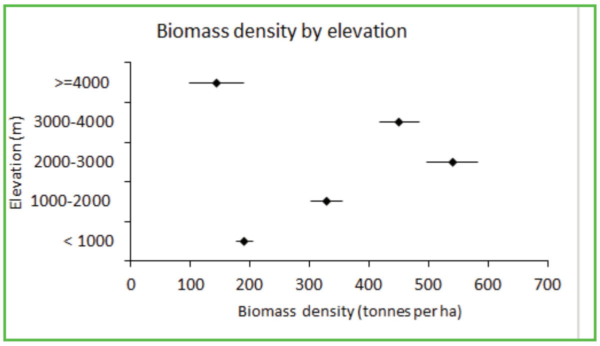


Figure 50: Biomass density by elevation range

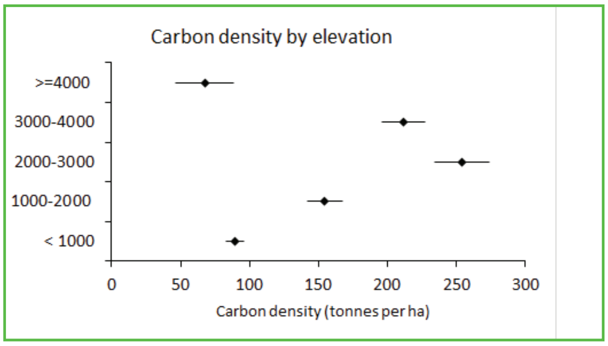


Figure 51: Carbon density by elevation range

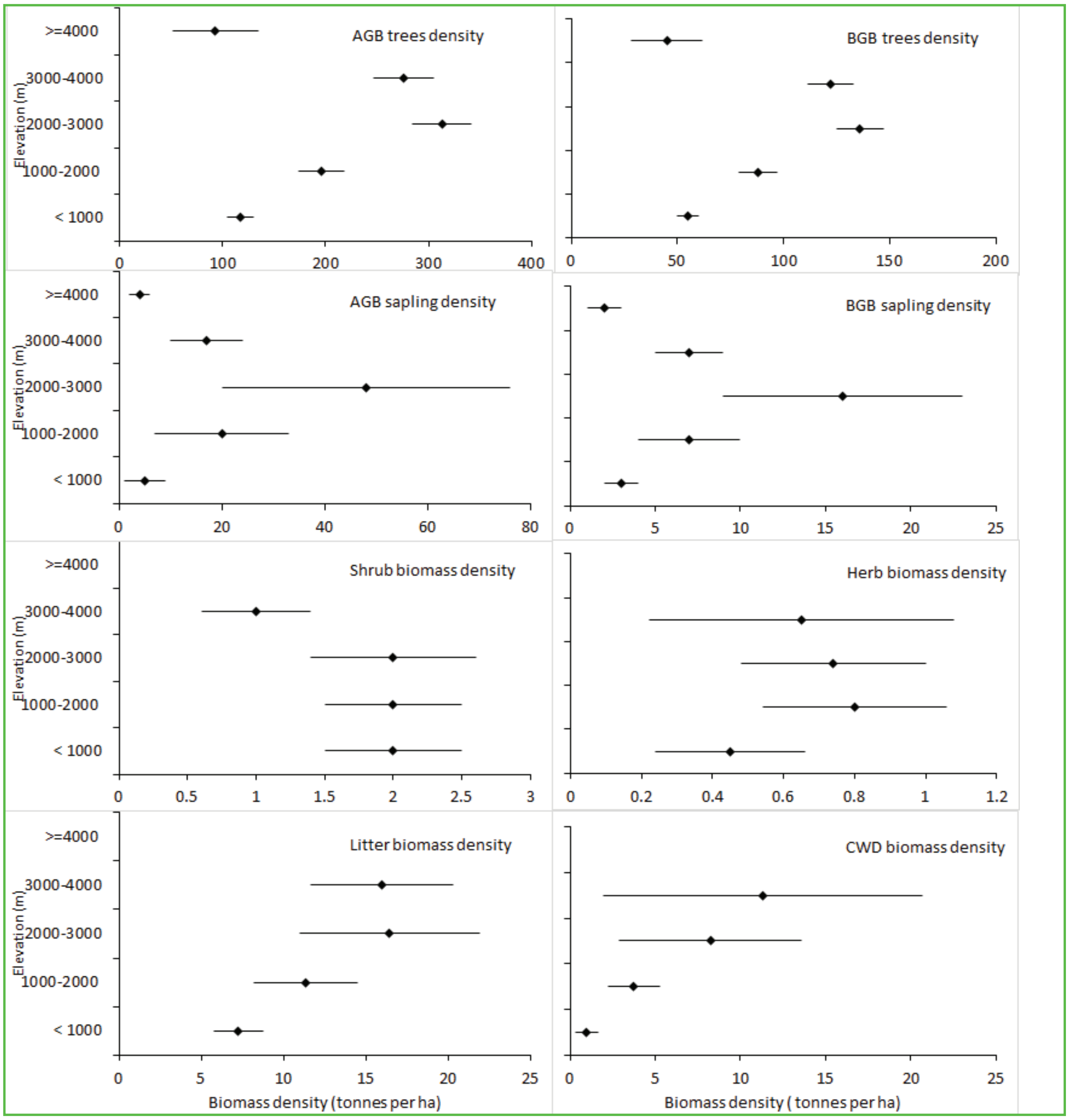


Figure 52: Biomass density of carbon pool constituents by elevation

2.4.2 Soil organic carbon by elevation

Soil organic carbon density also shows a unimodal distribution with elevation for all soil depth layers, as can be seen in Figure 54. Like trees, SOC density peaks at 2000-3000 m elevation. For the total depth of 30 cm, the SOC density increases from 18 t/ha at less than 1000 m elevation to 36 t/ha at 2000-3000 m and then decreasing slightly to 32 t/ha. This could be explained by the fact that SOC is greatly influenced by the litter deposited over the soil, which in turn is influenced by the type of AGB (Rasel, 2013) that is affected by the elevation.

Such trend in SOC is supported by another study carried out in Western and Central Bhutan by Simon et al. (2018).

The total SOC content is estimated to be greatest at 2000-3000 m elevation with total of 67 million tonnes of SOC and least at elevation range less than 1000 m of 17 million tonnes (Figure 53). At all elevation range, the SOC (both total and density) are seen to decrease with depth (Figure 53 ,55 and 56).

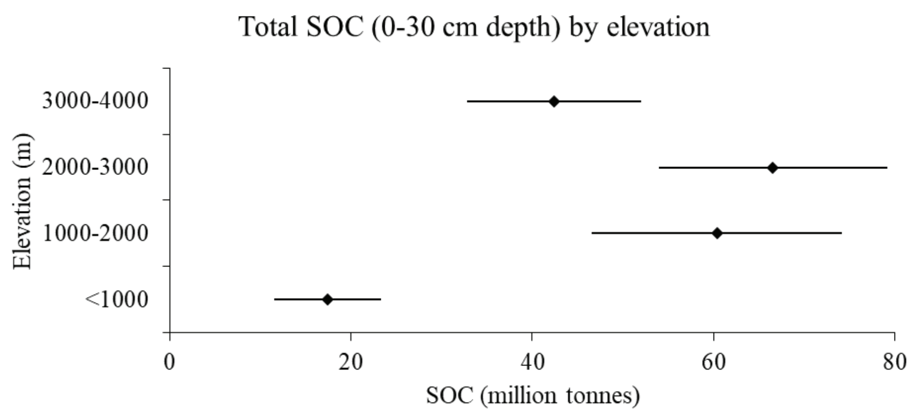


Figure 53: Total SOC within a depth of 30cm by elevation

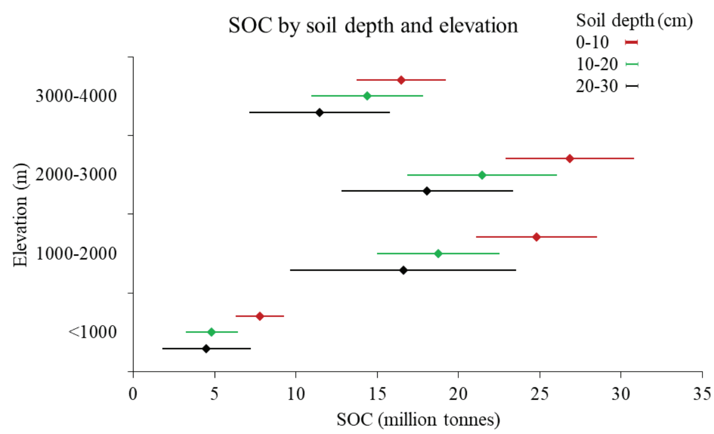


Figure 54: Comparison of total SOC at different soil depth at varying elevation range

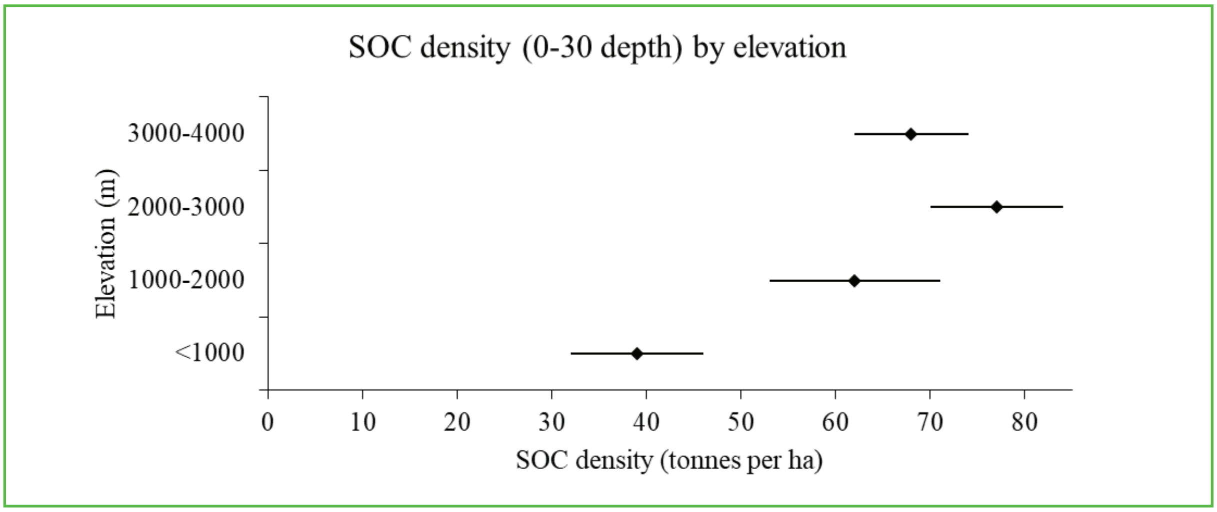


Figure 55: SOC density within 30cm depth by elevation

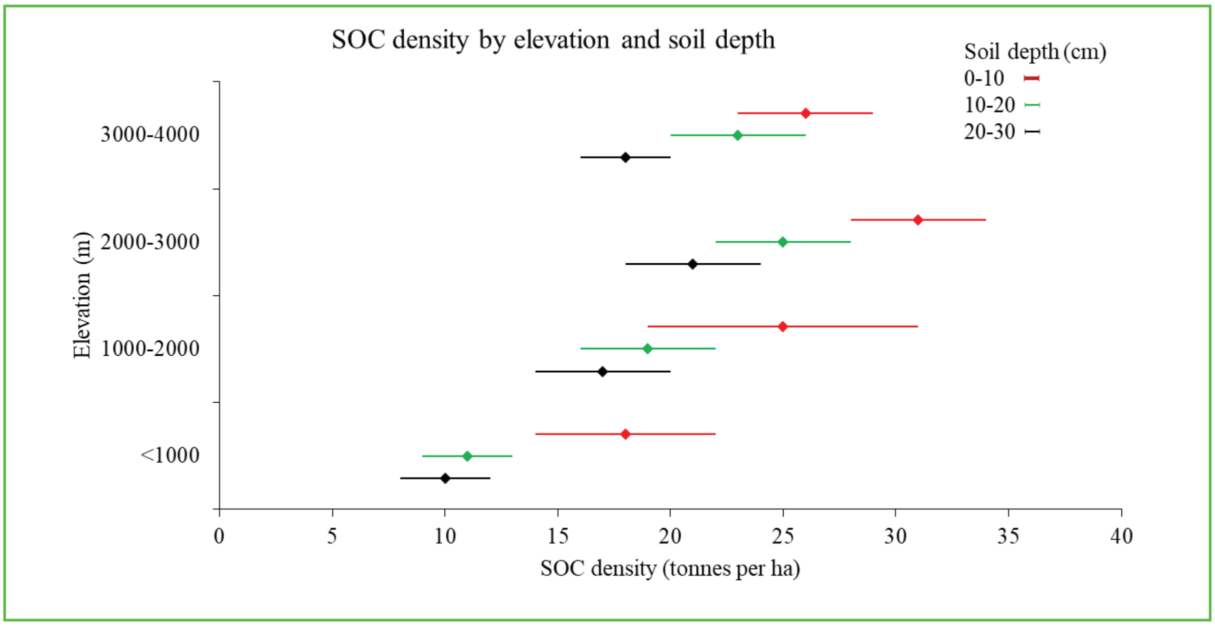


Figure 56: Elevation wise SOC density at different soil depth

2.4.3 Discussion

Changes in forest biomass and carbon density in general have a unimodal distribution over elevation range, where the biomass/carbon density peaks at mid-elevation range and then drops at the highest elevation. In case of Bhutan, the peak is at 2000-3000 m elevation range for both biomass and carbon. This elevation range corresponds to cool broad-leaved forest which has the greatest total biomass among the forest types and therefore signifying correlation of elevation with vegetation composition.

Factors such as temperature and precipitation associated with the elevation could be the underlying factors influencing the distribution pattern of biomass and carbon.


@Ugyen Penjor, NCD, DoFPS

CHAPTER 03

REGENERATION AND INCREMENT

Forest growth refers to the increase in dimensions of one or more individuals in a forest stand over a given period of time. The component of forest growth are increment (growth on trees present at both terminals of the growth period), mortality, cut and ingrowth (regeneration). Having the information on the forest growth is the heart of sustained yield management. A key condition for ensuring sustainable supply of forest resources is a forest management based on the correct assessment of resources which includes growing stock and regeneration pattern and harvesting plan based on information on increment rate of the forests (Tenzin *et al.*, 2017a; Tenzin *et al.*, 2017b). Information on diameter increment and growth patterns (regeneration) are required for planning. Forest management activities such as prescribing silviculture treatments as well as estimating rotational harvesting limit and cycles for tree species under consideration. The successful regeneration after harvesting or any natural disturbances is keystone for sustainable forest management.

The regeneration status presented in this report are based on the data collected through the national forest inventory plots (FRMD, 2012). Regeneration is classified as recruits, un-established and established as per the inventory manual (FRMD, 2012). 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.While the regeneration information can be obtained from the forest inventories, the information on the increment can be gathered by repeatedly measuring marked trees on permanent sample plots. However, if no repeated tree records are available, increment cores are the best option for deriving increment, provided that distinct annual tree rings are available which can be correlated to tree age (Tenzin *et al.*, 2017a). Thus, the increment rate presented in this report are derived from the increment cores collected from the national forest inventory plots. Increment cores were collected from every diameter class of every tree species within the plots as per the established dendrochronology manual (UWICER, 2017).

Although, rate of increment can be reported by diameter or basal area or volume, the most preferred is diameter/or basal area increment. The reported diameter/basal area increment can be converted to volume increment. Further, the context in which the value (increment) is to be used, also needs to be taken in to consideration. For instance, diameter increment rates would be suitable, if the increment is just needed to understand how the trees are growing, while for modeling tree growth, basal area increment are used mostly (West, 1980; Tenzin *et al.*, 2017a).

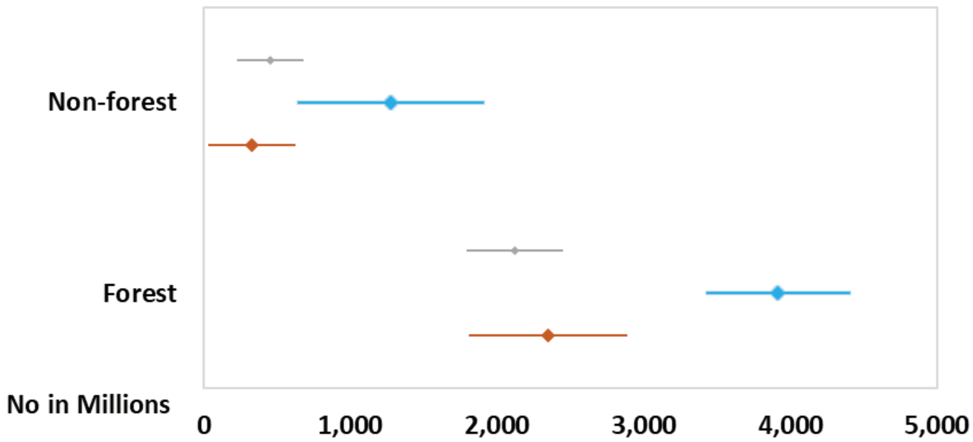
Basal area increment is also preferred as it takes in to consideration increment rates with respect to size of the tree (bigger trees will have smaller increment while smaller trees have larger increment. The diameter increment can be re-calculated from the basal area increments. Therefore, for this report, we report our increment rates as basal area increment. The increment was measured on a 5-year growth ring and accordingly, an annual basal area increment (BAI) was calculated for increment added every year.

Additionally, given the role of forests as a significant terrestrial sink for carbon dioxide, it was of interest to estimate the annual sequestration capacity of our forest. Therefore, this report presents the annual above-ground biomass increment (AGBI) of our forests and non-forests.
The information on the regeneration and increment of our forests from this report will serve as baseline for future comparison. It can also be used to measure how successful our plans and policies for forest management and improvement have been over the years. The results at the Dzongkhag level will also help to prioritize where more improvement of forests are required.

3.1 Regeneration

3.1.1 Regeneration at the national level

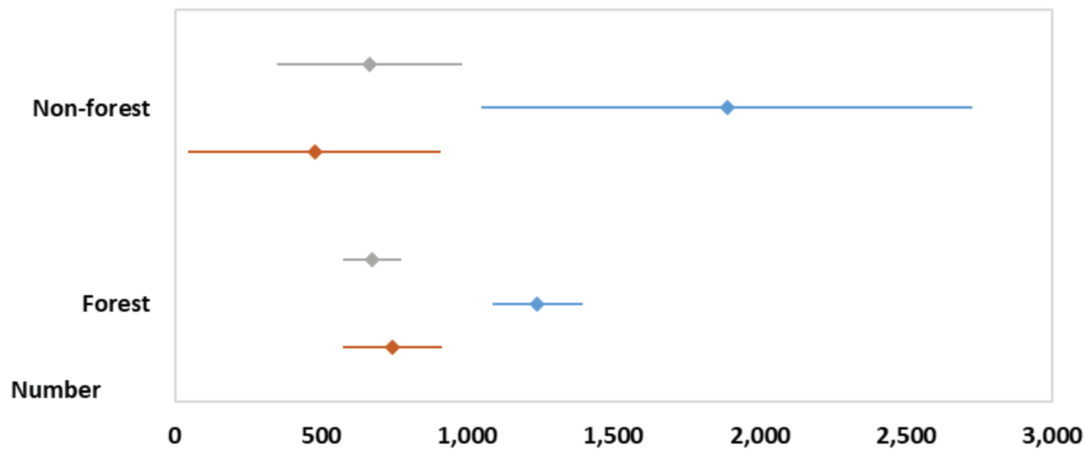
Regeneration data was collected from the elbow plot of the cluster plots across the country. The total number of regeneration significantly varies in forest and non-forest areas. The total number of regeneration in terms of recruits, un-established and established regeneration in the forests areas are 2349 million, 2123 million and 3916 million respectively while in the non-forest areas, it is 330 million (recruits), 457 million (un-established) and 1276 million (established) regeneration (Figure 57).



	Forest	Non-forest
Un-established	2,123,163,196	457,469,400
Established	3,916,087,746	1,276,985,134
Recruits	2,349,091,335	330,238,646

Figure 57: Total regeneration in forest and non-forest

The regenration density per hectare differs between forest and non-forests (Figure 58). The density of recruits (746 nos/ha) are greater in the forest area as compared to non-forest areas (478 nos/ha). However, the established regeneration density is greater in the non-forest (1889 nos/ha) than the forest (1240 nos/ha).



	Forest	Non-forest
Un-established	674	666
Established	1,240	1,889
Recruits	746	478

Figure 58: Regeneration per hectare in forests and non-forest

3.1.2 Regeneration by Dzongkhag

Bumthang and Gasa have the greatest number of recruits as compared to other Dzongkhags although lesser number of un-established and established regeneration. The lesser number of established and un-established seedlings despite higher number of recruits indicates higher mortality of seedlings (possibly due competition or other anthropogenic factors) in Bumthang. Punakha has the greatest number of established regeneration (2268) followed by Paro (2248), Lhuentse (2060), Haa (1929) and Wangduephodrang (1875) (Figure 59). Paro has the greatest number of un-established regeneration (1924) as compared to other Dzongkhags. Pemagatshel, Sarpang and Chukha have comparatively less regeneration in all categories as compared to other Dzongkhags.

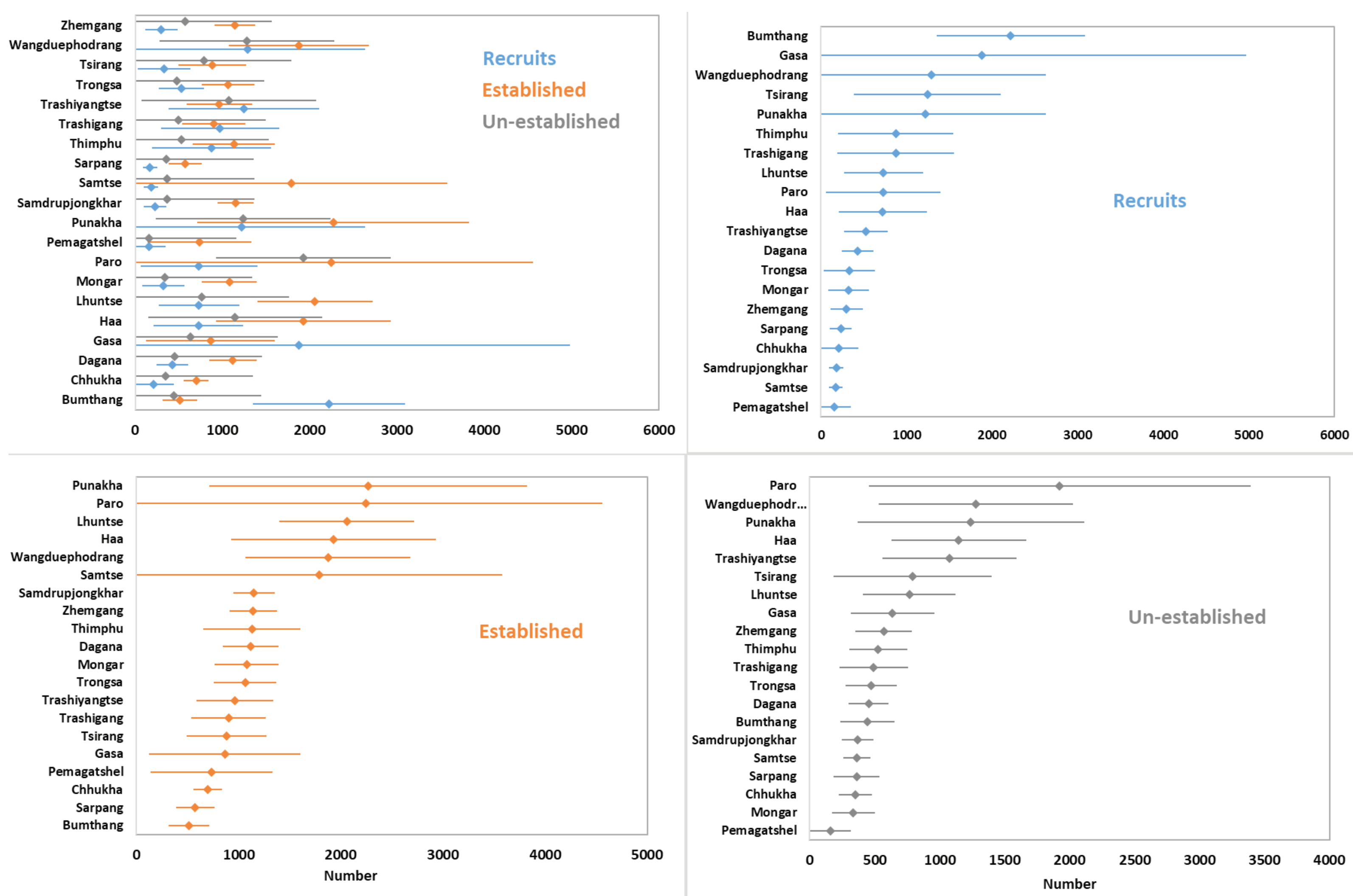
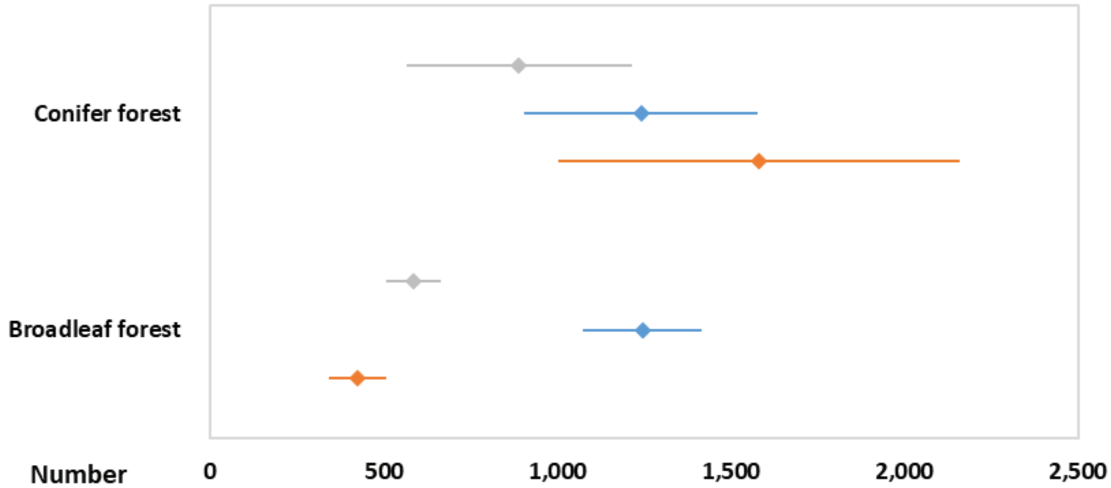


Figure 59: Regeneration per hectare by Dzongkhag

3.1.3 Regeneration by Forest type

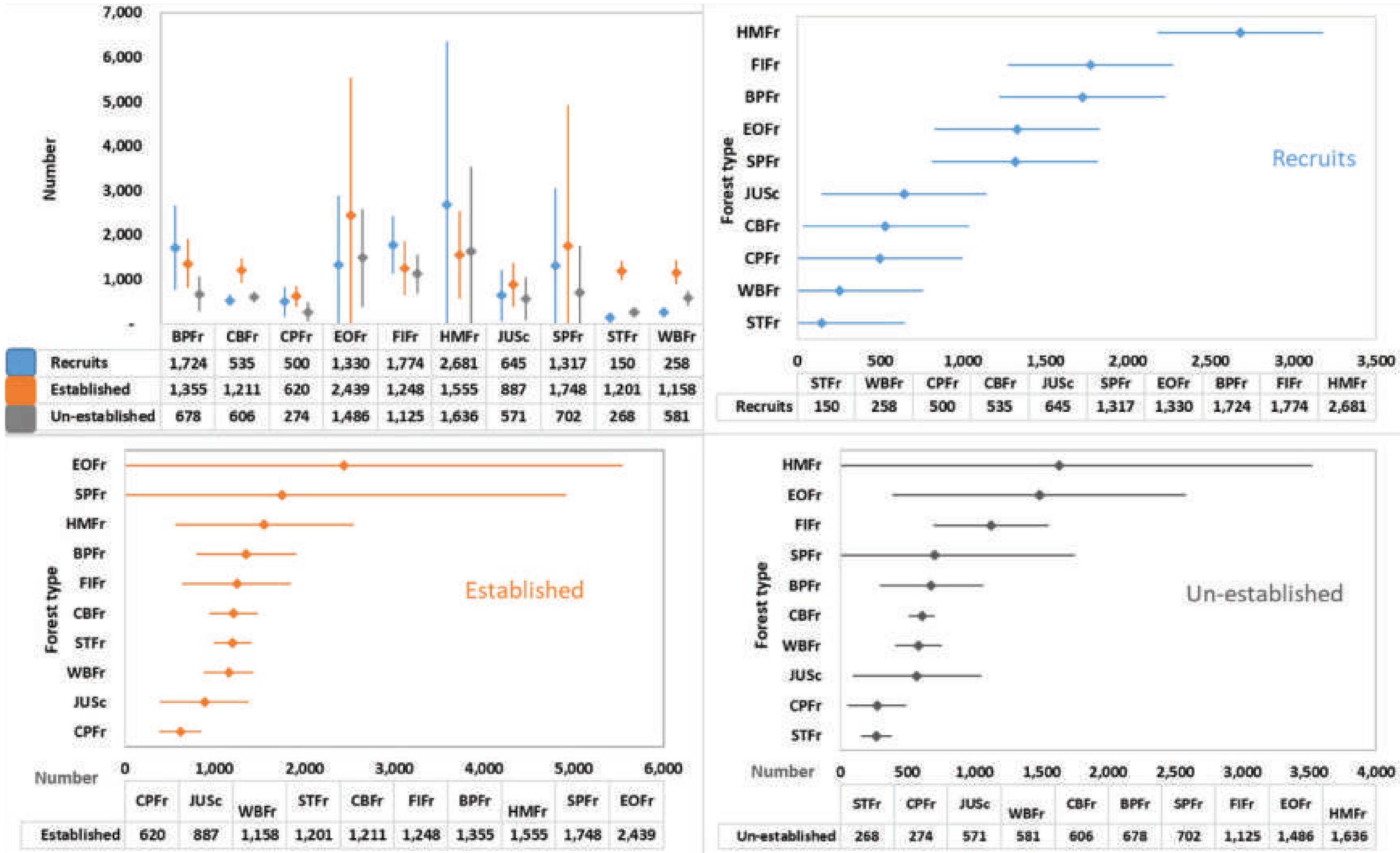
The regeneration of the forests in the two forest types (broadleaf and conifer) are not much different except for the recruits which are significantly higher in the conifer forests than the broadleaf forests (Figure 60).



	Broadleaf forest	Conifer forest
Un-established	587	890
Established	1,246	1,241
Recruits	426	1,583

Figure 60: Regeneration per hectare in broadleaf and conifer forest

The forest types were further segregated to ten different types (based on the dominating species) to see the trend in the regeneration pattern (Figure 61). Evergreen oak forest (EOfr) has the maximum established regeneration (2439). This is closely followed by spruce forests (SPfr) and hemlock forests (HMfr) with 1748 and 1555 of established regeneration. The number of recruits are significantly higher in the conifer type forests, except chir pine which is less than 1000. The evergreen oak forest (EOfr) has the highest recruits as compared to the other forest types in the broadleaf category.



	BPFr	CBFr	CPFr	EOFr	FIFr	HMFr	JUSc	SPFr	STFr	WBFr
Recruits	1,724	535	500	1,330	1,774	2,681	645	1,317	150	258
Established	1,355	1,211	620	2,439	1,248	1,555	887	1,748	1,201	1,158
Un-established	678	606	274	1,486	1,125	1,636	571	702	268	581

	STFr	WBFr	CPFr	CBFr	JUSc	SPFr	EOFr	BPFr	FIFr	HMFr
Recruits	150	258	500	535	645	1,317	1,330	1,724	1,774	2,681

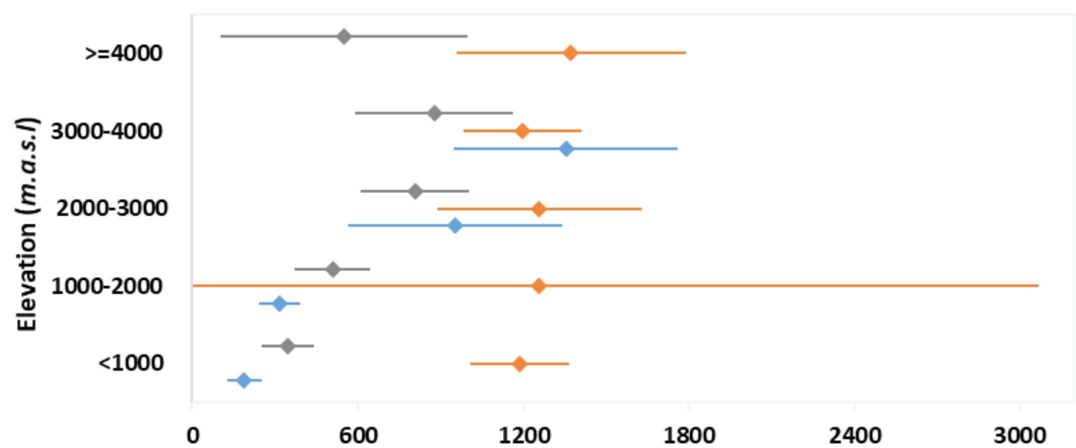
	CPFr	JUSc	WBFr	STFr	CBFr	FIFr	BPFr	HMFr	SPFr	EOFr
Established	620	887	1,158	1,201	1,211	1,248	1,355	1,555	1,748	2,439

	STFr	CPFr	JUSc	WBFr	CBFr	BPFr	SPFr	FIFr	EOFr	HMFr
Un-established	268	274	571	581	606	678	702	1,125	1,486	1,636

Figure 61: Pattern of regeneration in different forest types

3.1.4 Regeneration by elevation

The regeneration capacity is best at the elevations between 2000-4000 m (Figure 62). While there is comparatively equal number of un-established and established regeneration at all elevation, there is high sprouting of recruits at the elevation between 3000-4000 m, followed by the elevation range of 2000-3000 m. The greater number of recruits may be explained by the occurance of the cool broadleaf forest, evergreen, blue pine, spruce, fir and hemlock forest types found in this elevation range, which showed higher number of recruits as explained in the previous sections. The sub-tropical forest (<1000) has significantly lower number of recruits as compared to other elevation ranges. There is also no record of recruits in the dry alpine scrub (≥ 4000 m).



	<1000	1000-2000	2000-3000	3000-4000	>=4000
Un-established	346	509	808	878	549
Established	1188	1256	1259	1197	1374
Recruits	188	318	952	1354	0

Number

Figure 62: Regeneration per hectare at different elevations

3.1.5 Regeneration by species

The regeneration pattern by different species varies across the sites of forests and non-forests. The regeneration of 28 major tree species as reported in NFI volume I are reported individually, while the rest of the species are reported as "others".

Overall, the conifer species (except *Larix*) dominates the regeneration in all three categories in both forests and non-forests areas (Figure 63). Fir is having the maximum recruits and unestablished seedlings in both forests and non-forests but with lower established seedlings, which indicates lower establishment of fir seedlings. From the broadleaf category, the species such as *Acer, Belschimedia, Quercus, Rhododendron* and *Alnus* are having good regeneration in both forests as well as non-forests areas. Species from the other category has the maximum established regeneration in both forests and non-forests, while species such as *Juniper, Larix, Rhododendron* and

Magnolia have higher established seedlings in the non-forest areas, which explains the higher established seedling density in the non-forests area as seen under section 3.1.1. The important primary broadleaf species such as *Persea, Castanopsis, Quercus, Acer, Schima wallichii* and *Magnolia* are having lower regeneration as compared other species which mostly consists of secondary species. Moreover, these primary species regeneration are mostly confined to forest areas.

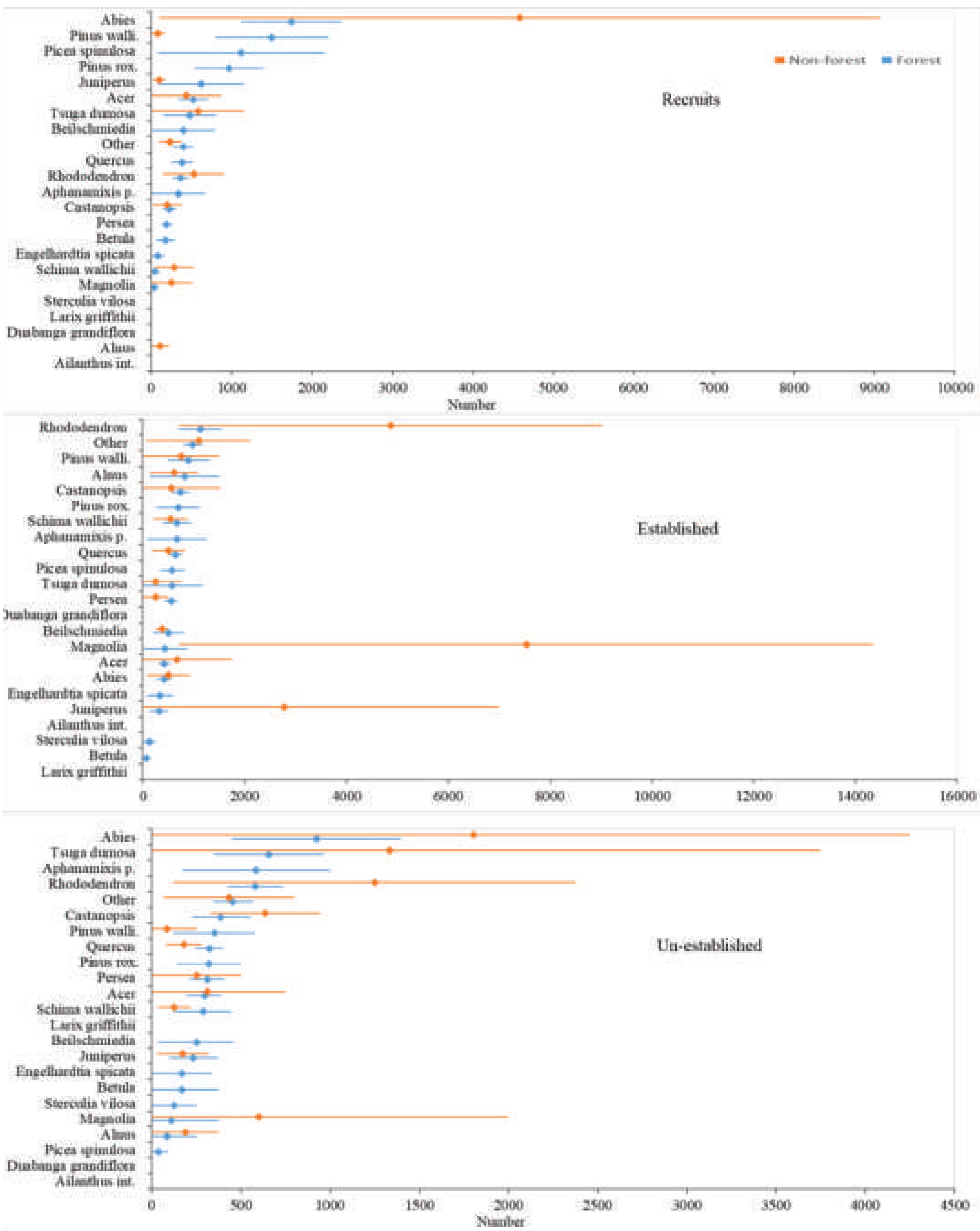


Figure 63: Regeneration pattern of different species in forest and non-forest

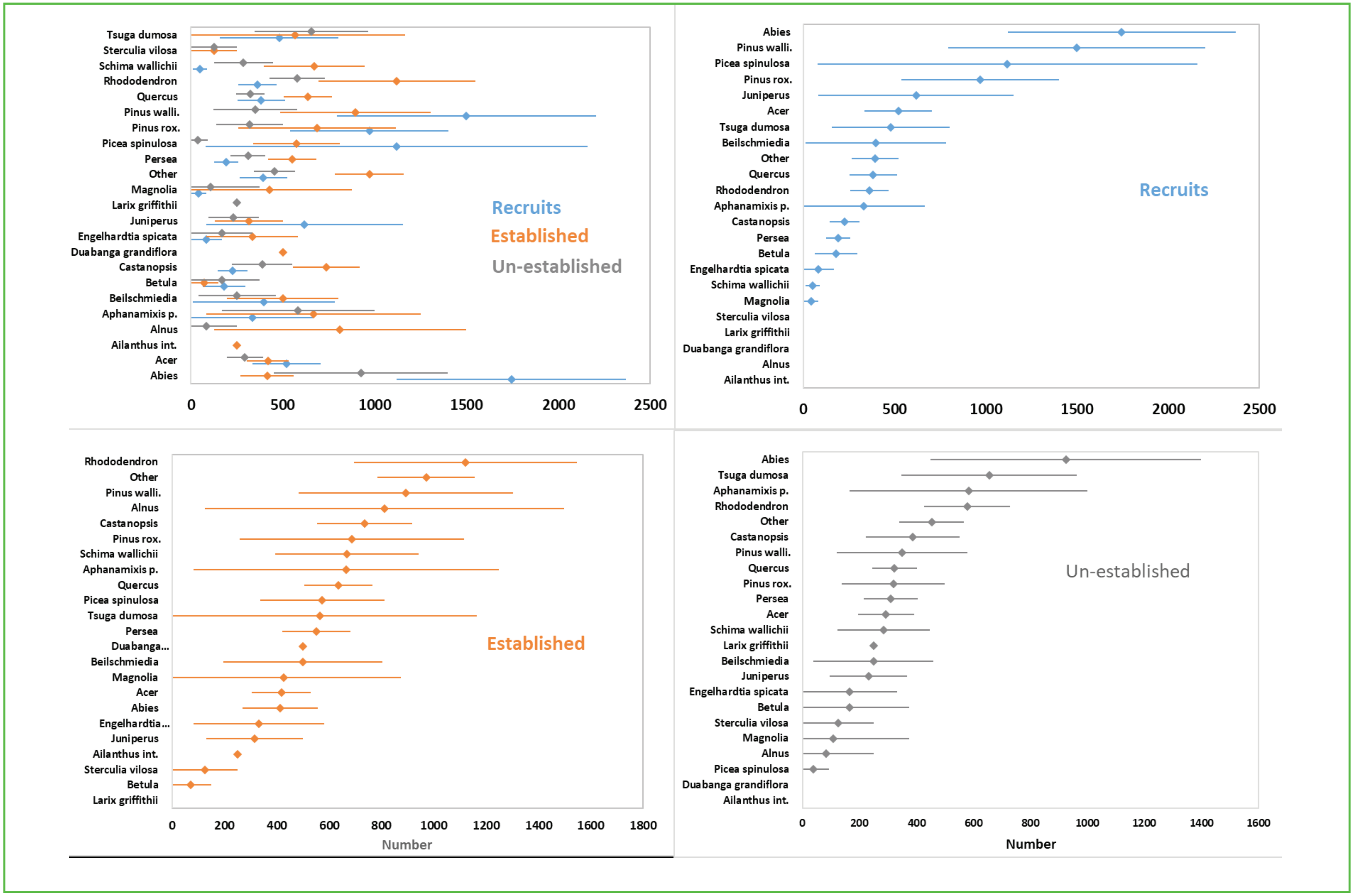


Figure 64: Pattern of regeneration of different species in forest

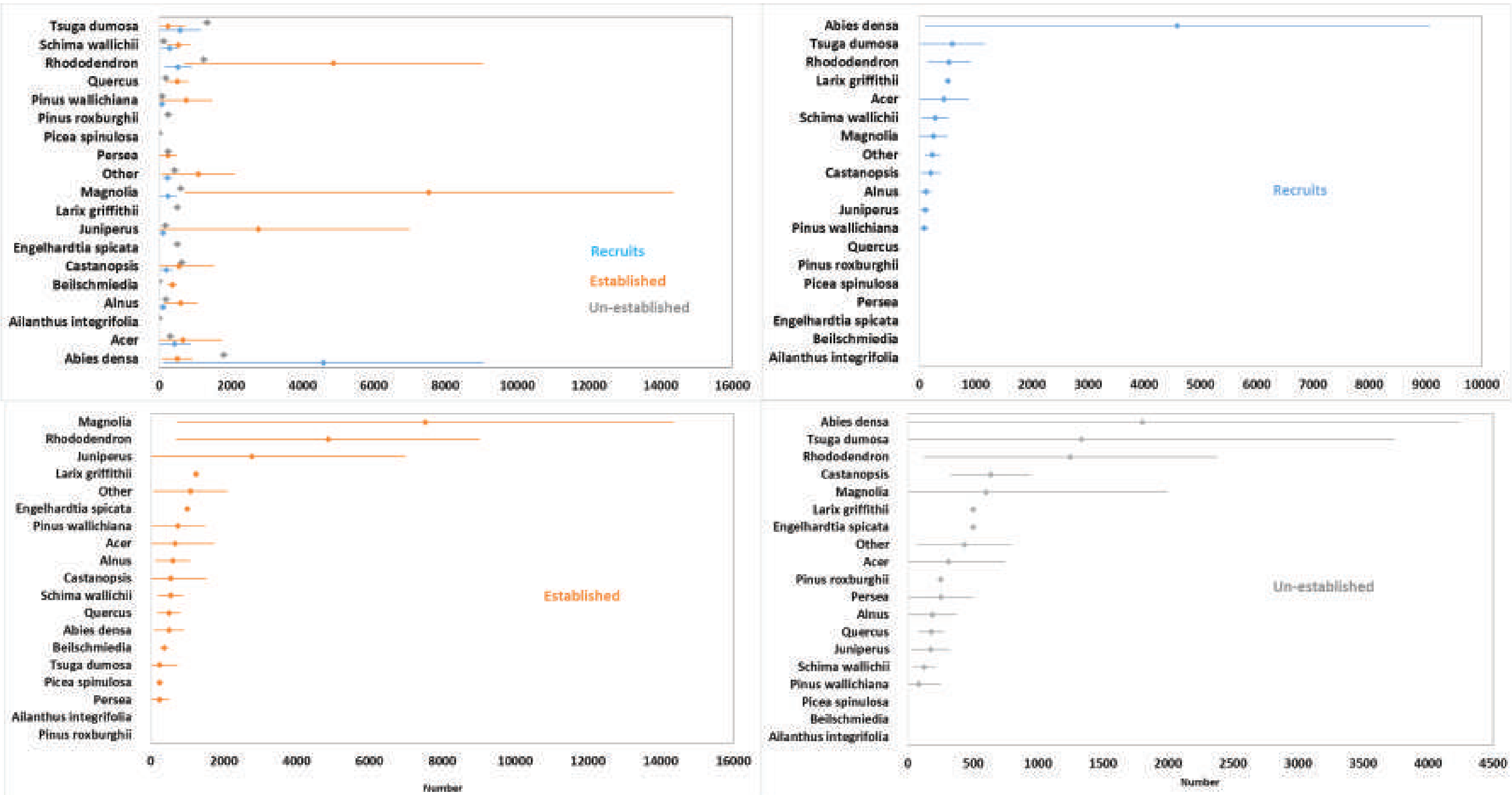


Figure 65: Regeneration pattern of different species in non-forest

3.1.6 Discussion

Natural regeneration occurs only with an adequate supply of viable seeds landing on suitable sites for germination. The greater number of total regeneration in the forest area is due to bigger areas under forest (71 %) than the non-forest category (29%) as reported in National Forest Inventory report volume I (FRMD, 2016). Similarly, the greater density of recruits in the forests areas as compared to non-forest areas is explained by greater density of trees in the forests (Petrokofsky *et al.*, 2012) (FRMD, 2016). However, the seedling density of the forests is at the lower range in comparison to the seedling density of forests of Uttarakhand, India (Rawat *et al.*, 2014).

As reported in earlier studies, the availability of space in the non-forests areas seems to have favored the establishment of the seedlings in non-forests areas as there are more established seedlings in the non-forests than forest areas. Tenzin and Hasenauer (2016) also reported greater density of established seedlings in the open areas than dense forests, which was mainly due to fast growing tree species overtaking the open areas and getting established. Tree numbers drop rapidly under the closed forest canopy as compared to open conditions provided that seeds are not limited and, microsites and the microclimate are suitable for the tree species (Coates, 2002). Similarly, the high forest cover and tree density per hectare in Sarpang, Chukha and Pemagatshel as compared to other Dzongkhags (FRMD, 2016) could be the possible reason for lesser regeneration in these three Dzongkhags. They also are located at the elevation range below 2000 m and mostly broadleaf forests, which also reported lower regeneration as compared to the conifer forests. This information on the lower regeneration in the Dzongkhags provides opportunity to properly analyze and carry out the necessary interventions.

The opening in the forests promotes understory constituents which inhibit the regeneration of shade-intolerant species and instead favors the growth of shade-tolerant species such as Hemlock and Spruce (Tenzin, 2008). This explains the greater density of seedlings in these two forests types. Fir has the maximum density of recruits and considerable density of established seedling. A similar study in Nanda Devi, India found maximum regeneration in *Abies pindrow* (western Himalayan fir species), with 1195 seedlings/ha followed by 400 seedling/ha in *Abies* spectabilis (Joshi and Samant, 2004). The number of established regeneration of blue pine is a little greater than the number of established regeneration of Bluepine (390.59-703.25 seedling/ha) observed in Kashmir between the altitudinal range of 2000-3200 m (Bhat *et al.*, 2015). Joshi (2009) recorded about 367 no/ha in the temperate region (1800-2800 m) and 642 no/ha in sub-alpine region (2800-3800) in the Indian Himalayas.

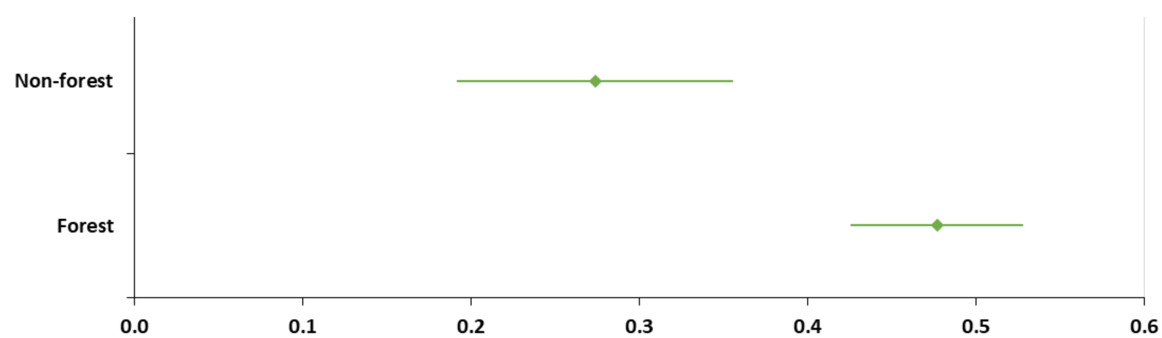
Regeneration in the forests of Bhutan have been reported as the combined effects of opening sizes, competing understory vegetation, and cattle browsing on seedling establishment (Darabant, 2005). The lesser number of regeneration in the broadleaf forests could be combination of all these factors, which needs further study for coming up with appropriate recommendations. Broadleaf forests have a diverse flora and fauna sub-types resulting in innumerable complex ecosystems. Regeneration in forests (especially broadleaf) of Bhutan is therefore a concern, whereby anthropogenic factors and grazing are reported as severe causes of regeneration failure (Wangda and Ohsawa, 2006a; Buffum *et al.*, 2008), while the same (control grazing) is reported to promote regeneration in conifer forests (Darabant *et al.*, 2007). In general, tree species are less resistant to browsing than grasses, forbs and shrubs and are easily eliminated by browsing. Further, Moktan *et al.* (2009) reported that conifer seedling remains largely intact from browsing due to the presence of terminal shoots and lateral branches. The seedling of the temperate conifer are less palatable or unpalatable, resulting in negligible effect from grazing (Moktan *et al.*, 2008) and hence, greater number of established regeneration. The broadleaf species, especially the primary species such as *Acer, Castanopsis, Quercus* and *Beilschmiedia* are having lesser number regeneration as compared to the "other" species, thus the primary species might be little represented in the lower diameter class. Ideally, more number of regeneration of the primary species is expected but the results here shows that composition of the regeneration is skewed towards the pioneer species and could be due to management disturbances or grazing disturbances. Ohsawa (1991), Norbu (2002), Buffum *et al.* (2008) and Tenzin and Hasenauer (2016) also describes similar retrogressing ecological succession in broadleaf forests of east (Lingmethang and Korila), west (Gedu) and south central (Dagana) due to anthropogenic disturbances.

Since, the successful regeneration after harvesting or any natural disturbances is a keystone for sustainable supply of resources, the information reported here can be used as basis for future monitoring and current management of the regeneration in the forests and non-forests.

3.2 Forest increment

3.2.1 Annual increment at the national level

The basal area increment (BAI) of the forest and non-forest areas differs significantly (Figure 66). The annual basal area increment (ABAI) for the trees in the forest areas is 0.48 m^2/ha while for the non-forest areas it is 0.27 m^2/ha at 90 % confidence level, which indicates that the trees are growing faster in the forest areas than in the non-forest areas.



	Forest	Non-forest
BAI per ha	0.48	0.27

m²/ha/year

Figure 66: BAI per hectare in forest and non-forest

Similarly, the annual above-ground biomass increment (AGBI) for trees in forest is greater in forest than non-forest. The annual above-ground biomass increment per hectare is estimated to be 2.01 t/ha and 1.25 t/ha in forest and non-forest respectively.

3.2.2 Increment by Dzongkhag

The annual BAI per hectare of the forests when presented by Dzongkhags ranges from 0.13 – 0.69 m^2/ha (Figure 67). Chukha saw the greatest annual BAI (0.69 m^2/ha) closely followed by Punakha (0.68 m^2/ha) and Lhuentse (0.66 m^2/ha). Gasa recorded the least increment, followed by Trashiyangtse (0.21 m^2/ha). Haa, Dagana, Trongsa, Paro, Wangduephodrang and Gasa have increment lesser than or equal to the national average of 0.48 m^2/ha.

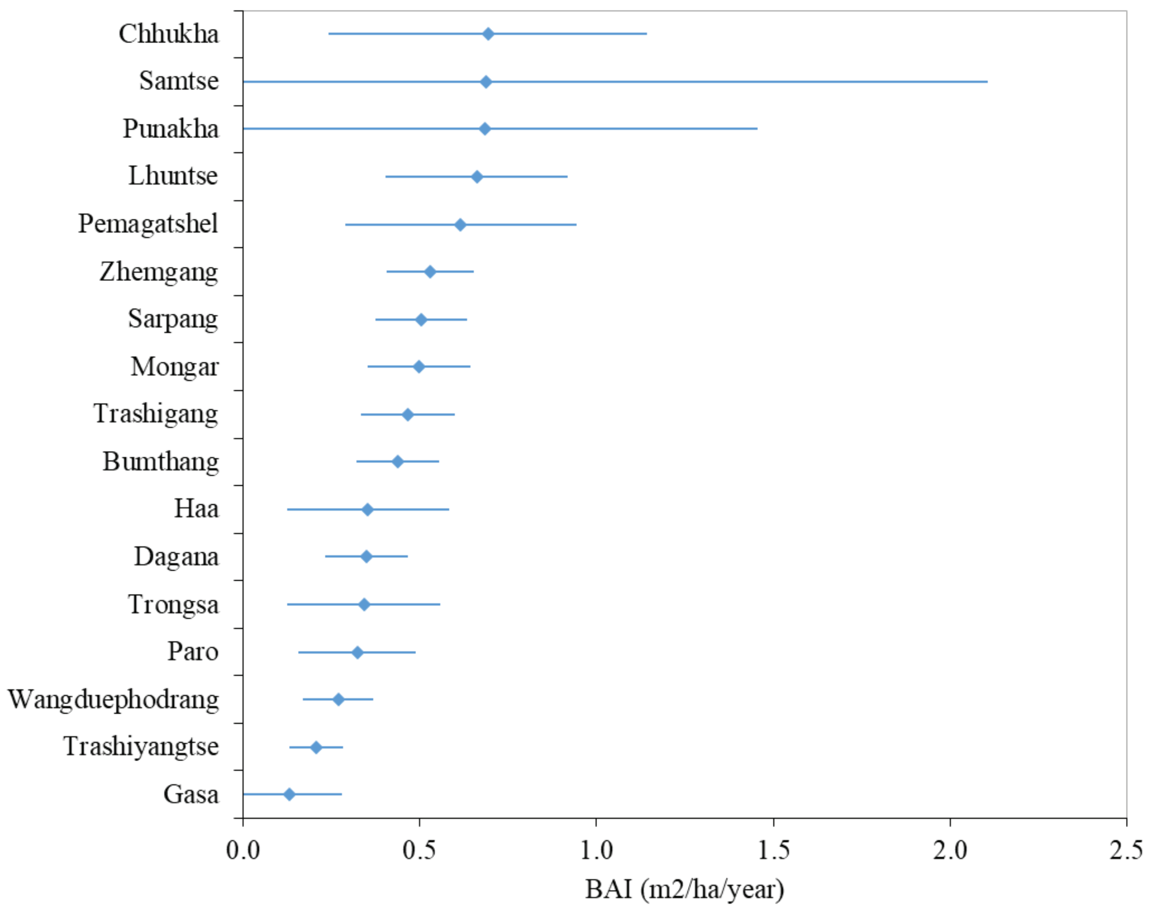
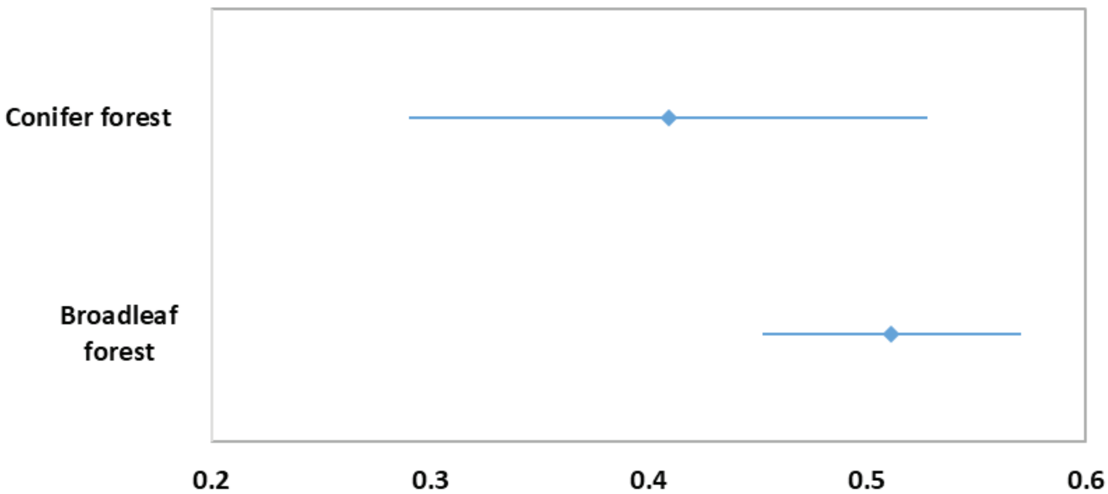


Figure 67: BAI per hectare by Dzongkhag

3.2.3 Increment by Forest type

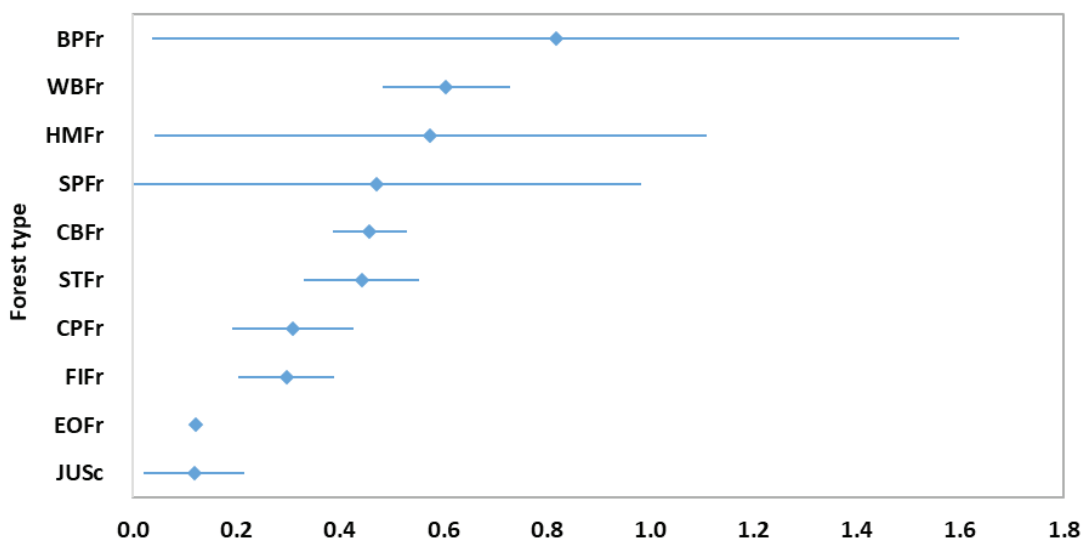
The annual BAI of the two major forest types over the past five year period are not significantly different though broadleaf forests (0.51 m^2/ha) seem to have a slightly greater BAI than conifer forests (0.41 m^2/ha) (Figure 68). The annual BAI is further analyzed for 11 forest types.



	Broadleaf forest	Conifer forest
BAI per ha	0.51	0.41

Figure 68 : BAI per hectare in broadleaf and conifer forest

The Blue pine forests (BPFr) with annual BAI of 0.82 m^2/ha has the greatest BAI per ha followed by the Warm broadleaf forests (WBFr) with 0.61 m^2/ha. The Evergreen oak forest (EoFr) along with the Juniper Rhododendron Scrub forest (JUSc) has the least BAI per ha (0.12 m^2/ha) (Figure 69). From the conifer forests, the Fir and JUSc have recorded very slow growth over the past five year period.



	JUSc	EOFr	FIFr	CPFr	STFr	CBFr	SPFr	HMFr	WBFr	BPFr
BAI per ha	0.12	0.12	0.30	0.31	0.44	0.46	0.47	0.58	0.61	0.82

Figure 69: BAI per hectare in different forest types

3.2.4 Increment by Elevation

The annual BAI per hectare increases from elevation range of below 1000 m and peaks in the elevation range of 1000-2000 m and then drops as the elevation increases above 2000 m (Figure 70). The lowest BAI (0.35 m^2/ha/year) is observed in the higher altitude between 3000-4000 m. The basal area increment peaks in the warm broadleaf and chirpine forest in 1000-2000 m, with an annual BAI of 0.57 m^2/ha, followed by a slight decrease in the sub-tropical forest (0.49 m^2/ha) below 1000 m.

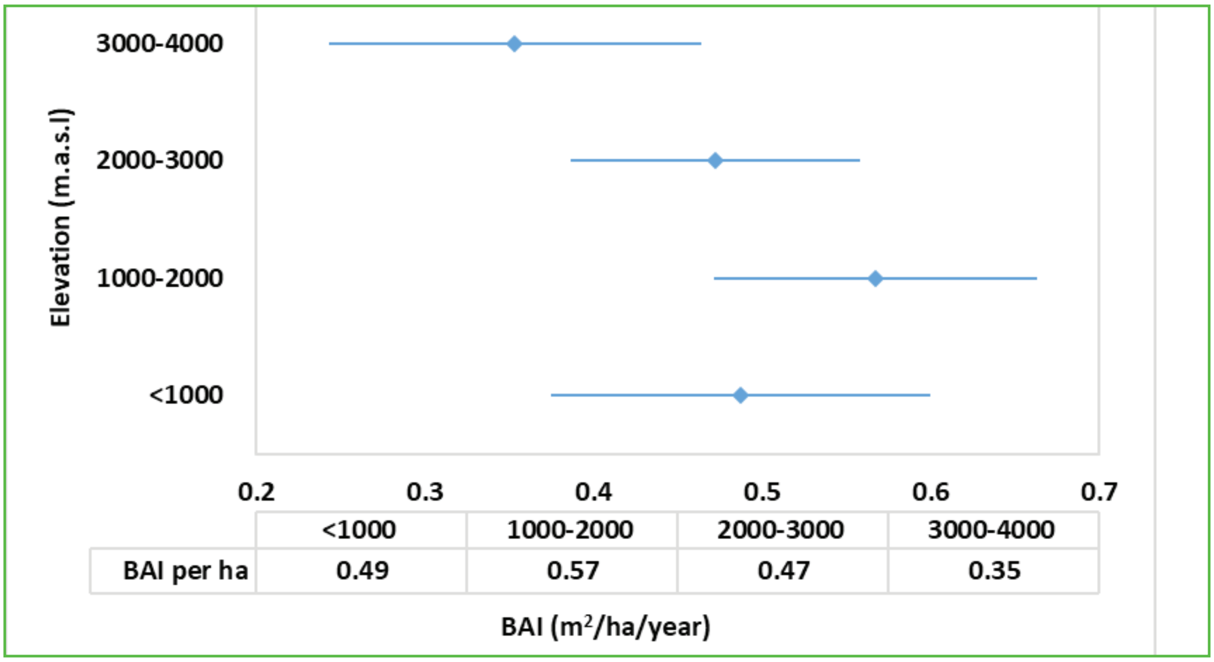


Figure 70: BAI per hectare at different elevations

3.2.5 Increment by species

The annual BAI per hectare by different species varies across the sites of forests and non-forests. In the forest area, the greatest BAI per ha is found in sub-tropical species like *Duabanga grandiflora* (0.16 m^2/ha) followed by *Tetrameles nudiflora* (0.13 m^2/ha) and *Alnus nepalensis* (0.11 m^2/ha). *Pinus wallichiana* (0.12 m^2/ha) followed by *Tsuga dumosa* (0.07 m^2/ha) have the greatest BAI per ha among the conifer species. Species belonging to the other category (0.07 m^2/ha) is also showing higher growth rates as compared to most broadleaf species in the forest areas. The primary important broadleaf species such as Persea, Betula, Acer, Castanopsis and Schima have recorded lower growth rates in the past five years. In non-forest area, BAI per ha is greatest in *Ailanthus integrifolia* (0.17) followed by *Pinus wallichiana* (0.16) and *Pinus roxburghii* (0.07). Species such as *Schima wallichii*, *Magnolia* and Juniper are showing greater growth in the non-forest areas as compared to forest areas. In general, light demanding species have more increment in the open non-forest areas.

Figure 71: BAI of major species in forest and non-forest

3.2.6 Discussion

The BAI growth of individual trees typically follows a sigmoidal pattern, whereby it increases rapidly from young to middle age, plateaus and remains level during a protracted period of middle age and then declines as trees become old age (Tenzin *et al.*, 2017a). The BAI is influenced by a combination of different factors viz., size (dbh, height, crown size), competition, age, bi-social position (Kaźmierczak, 2013), altitude (Coomes and Allen, 2007; King *et al.*, 2013), initial growth or diameter (West, 1980), climate and forest type (Sardans and Peñuelas, 2013; Butt *et al.*, 2014) amongst other factors. All these have an individual or a combined effect on the BAI put on by the individual tree and the stand, which explains the variation of the BAI in different forest types, Dzongkhags, the altitudinal gradients and species types as reported in this report.

The annual BAI per hectare is greater in forests (0.48 m^2/ha) as compared to non-forests (0.27 m^2/ha), which indicates the presence of faster growing tree species in the forests or less productivity of non-forests. Trees in higher elevation have less growth resulting in stunted growth and more open canopies (Coomes and Allen, 2007), which are classified as non-forests as per definition of forests and non-forests (FRMD, 2016). Overall, the ABAI of forests of the country is however lesser than BAI of managed forests in Australia, which is around 0.5 m^2/ha/year in Australia (Smith and Nichols, 2005). Similarly, the average value of BAI of 0.67 m^2/ha/year, when measured at the dbh of 1.37 m was reported for forests in northern Utah (Dean, 2004).

Elevation encompasses both temperature and humidity which are both decisive in vegetation distribution for a mountainous terrain like Bhutan. At the sub-national level, Chukha and Samtse Dzongkhags saw the greater BAI over the past five year period as compared to the other Dzongkhags. The two Dzongkhags of Chukha and Samtse have forest cover of 81 % and 60 % respectively and tree density of 220 per hectare and 136 per hectare (FRMD, 2016), which indicates favorable conditions for tree growth. The two Dzongkhags are predominated by broadleaf forest, which observed greater BAI as compared to conifer forest. Moreover, more than 70 % of the total area of Samtse falls below 2000 m, which has the greatest BAI.

The ABAI decreases with increase in elevation from 1000-2000 m.a.sl upwards, with the 3000-4000 m having the smallest ABAI. This is mainly due to gradual decrease in temperature and nutrients resulting in harsher climatic condition and reduced growing season in the higher elevation (Worbes, 1995). For instance Gasa has the least forest cover of 36 % (FRMD, 2016), which is dominated by conifer forest. And 95 % of the total area of Gasa is above 3000 m. The low temperature and snow-covered mountains provide very harsh environment for growth, resulting in the least BAI in the Dzongkhag. Coomes and Allen (2007) also confirmed decline in tree growth with increasing elevation. Thus Juniper scrub forests, which are located at higher elevation recorded the lowest BAI over the past five year period. Lack of moisture is also affecting the tree growth as Wangduephodrang also saw lower BAI over the five year period and this could be due to its location in the dry sites of the inner dry Himalayas valleys as reported by Ohsawa (1987) and Wangda and Ohsawa (2002).

BAI is greatest in the elevation range between 1000-2000 m, which is predominately the Warm broadleaf forest and the Chirpine forest. The elevation <1000 m has the BAI of 0.49 m^2/ha, which is mostly the subtropical forest. This could be due to higher stem density in the subtropical forest in the elevation <1000 m than the next elevation zone, which is Warm Broadleaf zone (FRMD, 2016). High stem density increases competition and will affect the annual increment of the trees. For instance Evergreen Oak forests recorded the least BAI as it has the highest stem density (367 tree per ha) as per NFI volume I report (FRMD, 2016). Hein and Dhôte (2006) recommended thinning of Oak to reduce the stand density and ultimately to ensure the increment in diameter and BAI.

Warm broadleaf forest (0.61 m^2/ha/year) shows the greatest ABAI over the past five years as compared to all other forest types except blue pine forest (0.82 m^2/ha/year). Mixed broadleaf stands will have higher stability against natural disturbances than pure conifer stands resulting in constant increment (Hein and Dhôte, 2006). However, the ABAI in the conifer forest of Bhutan is still greater than the average ABAI of 0.25 m^2/ha/year observed in boreal forest of Canada, where the ABAI ranges from 0.16 to 0.40 m^2/ha for major species (Pokharel and Dech, 2012). The recorded BAI per ha of 0.07 ±0.01, 0.12 ±0.13 and 0.04 ±0.02 for *Pinus roxburghii*, *Pinus wallichiana* and *Picea spinulosa* in the forests of Bhutan is almost equal to the European variant of Pine (Scots pine with 0.3l - 0.36) and Spruce (Norway spruce with 0.63 - 0.69) (Monserud and Sterba, 1996).

Pinus wallichiana showed the higher growth rates over the past five years as compared to all other species and forest types and it corresponds well with the findings by Rosset (1999), where the Blue Pine forests with annual volume increment ranging from 6 m^3/ha to 21 m^3/ha was far more productive than Hemlock (8 m^3/ha to 15 m^3/ha), Spruce (6 m^3/ha to 9 m^3/ha) and Fir (3 m^3/ha to 8 m^3/ha) in the temperate forests of Bhutan. In terms of broadleaf species, study done by Tenzin *et al.* (2017a) shows annual BAI per tree based on tree ring analysis, ranged from 0.00002 m^2/tree/year to 0.0134 m^2/tree/year for 87 broadleaf tree species grouped under four species groups. The higher BAI of the "other species" category as compared to most broadleaf species, especially the primary species indicates the presence of younger stand of the "other species" category. The regeneration of species in the other category was also observed higher as explained in section 3.1.6. Tenzin and Hasenauer (2016) also reported the presence of younger stand of the pioneer species especially in the semi-disturbed areas with opening for the pioneer species to establish.

The BAI information is provided here for the first time and can be used for improving forest management and planning in the country. The BAI can be improved with the implementation of the next national forest inventory, whereby actual annual increment can be obtained from the diameter increment between the two inventory periods. The availability of the growth information can be used for developing forest growth models consisting of height increment function, height diameter function, regeneration model and mortality model. An increment model similar to the one developed by Tenzin *et al.* (2017a) for the broadleaf forests of Dagana, can be developed or up scaled for the national level using the BAI and other inventory data. An important task of the increment models is that it can be used to predict tree growth relative to site and at different competition levels (Hasenauer, 2006; Tenzin *et al.*, 2017a), thus can help in improving forest management in the country.


@Ugyen Penjor, NCD, DoFPS

CHAPTER 04
SPECIES DIVERSITY

Forests are rich repositories of biodiversity and are important for providing services to society (Führer, 2000). Species composition/diversity are important indicators for biodiversity (Husch *et al.*, 2002) and may strongly depend and/or be influenced by the applied management practices. Species diversity of an area is strongly impacted by both natural and anthropogenic disturbances. The disturbances impact the biodiversity by influencing forest conditions and forests succession dynamics (Tenzin and Hasenauer, 2016). Anthropogenic impacts are expected to increase with the continued demand for forest resources and this will change old growth forest ecosystems into man made landscapes, leading to habitat fragmentation and declining species richness (McKinney, 2002). Assessments of forest biodiversity – the diversity within forest species, between species and of forest ecosystems – are essential if forest resources are to be effectively conserved and sustainably managed.

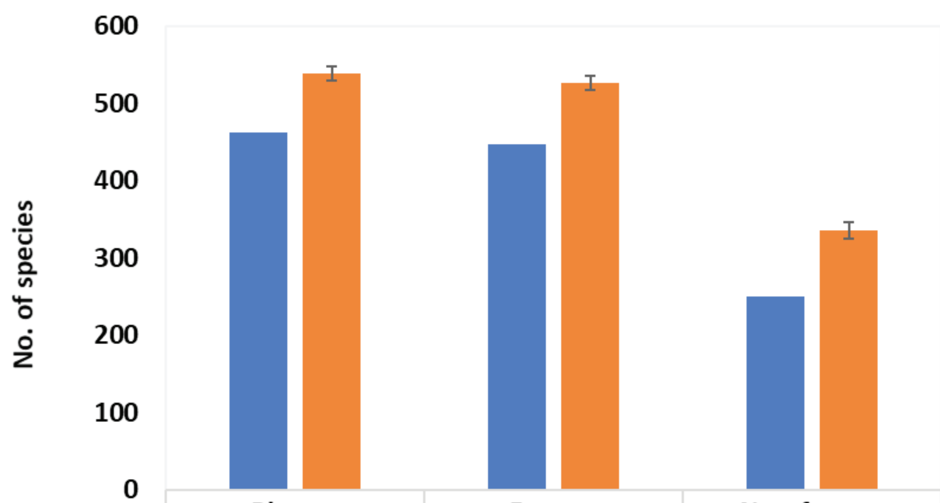
Forest biodiversity were assessed using indicators of Shannon index, Evenness index, Gamma and Betta index. The Shannon index (Shannon and Weaver, 1949) measures the number of species and their even distribution according to the proportion of species. Evenness (Pielou, 1969) indicates how even the species are distributed in the forest with values ranging from 0 to 1, where 1 means perfectly even distribution and values approaching 0 mean an uneven distribution or that the forest is dominated by one species. Evenness is important because it is both influenced by a different process than species richness, and is often associated with different suite of environmental factors.

Gamma index measures the total number of species within the geographic areas (which is equal to total number of observed species in the area) while the betta index measures the change in species diversity within the plots or the area. Species recorded via inventory plots is always smaller than the actual species richness of the area as certain species could be missed due to human error, environmental fluctuations that effect observations, or very small species detection probabilities (Smith and Pontius, 2006). In such cases, total species accumulation method in the form of Jackknife estimator was used to estimate (extrapolate) statistically the probable total species in the area of interest. The results of the various diversity indices presented here were generated following Oksanen (2017).

4.1 Species diversity and composition at the National Level

The species diversity and composition are reported at national level, Dzongkhag level, forest types and elevation. The diversity indices and species composition of our forests from this report will serve as baseline for future comparison. It can also be used to measure how successful our plans and policies for forest management and improvement have been over the years. The results at the Dzongkhag level will also help to prioritize where more improvement of forests health is required.

A total of 463 tree species (Gamma diversity) were recorded through the inventory plots spread across the country (Figure 72). This number only includes those species which were observed and identified by our field crews and experts. About 1968 observations from the total of 51,116 observations were recorded as unknown species (which couldn't be identified) and thus the actual tree species of the country is definitely greater than the reported 463 species. Considering the unknown species and also the species detection error or detection probabilities (Smith and Pontius, 2006), the total species in the country is estimated (Jackknife estimator) to be at 539 ± 9 (Figure 72). The overall mean diversity index of Shannon for the country were estimated as 1.05 while evenness is 0.17 (Figure 75). The lower evenness indicates unequal distribution of species, which means presence of certain tree species dominating the different ecosystems.



	Bhutan	Forests	Non-forests
Observed	463	448	250
Extrapolated	539	527	336

Figure 72: Observed and extrapolated number of species with SE for the country, forests and non-forests

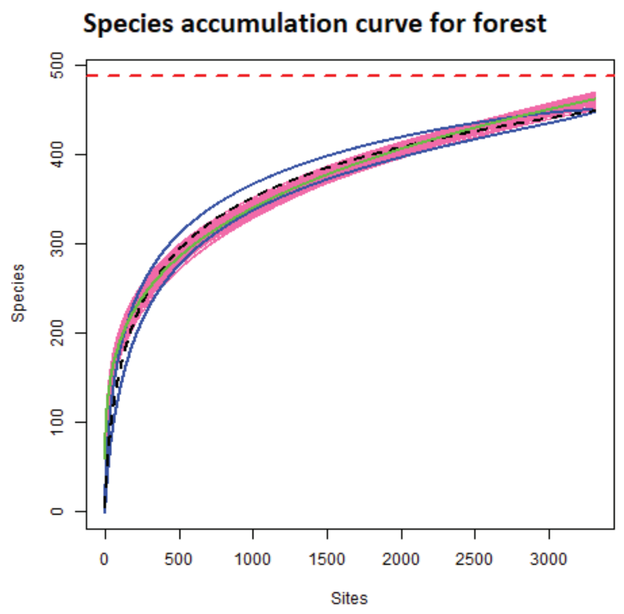


Figure 73: Species accumulation curve for forest

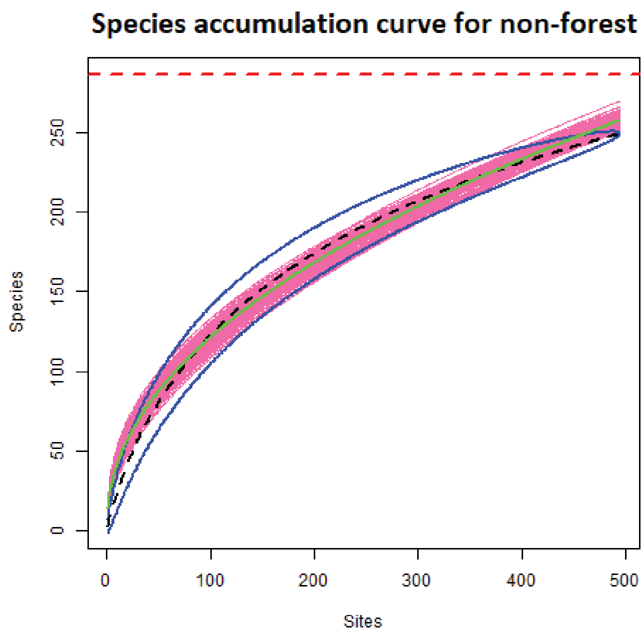
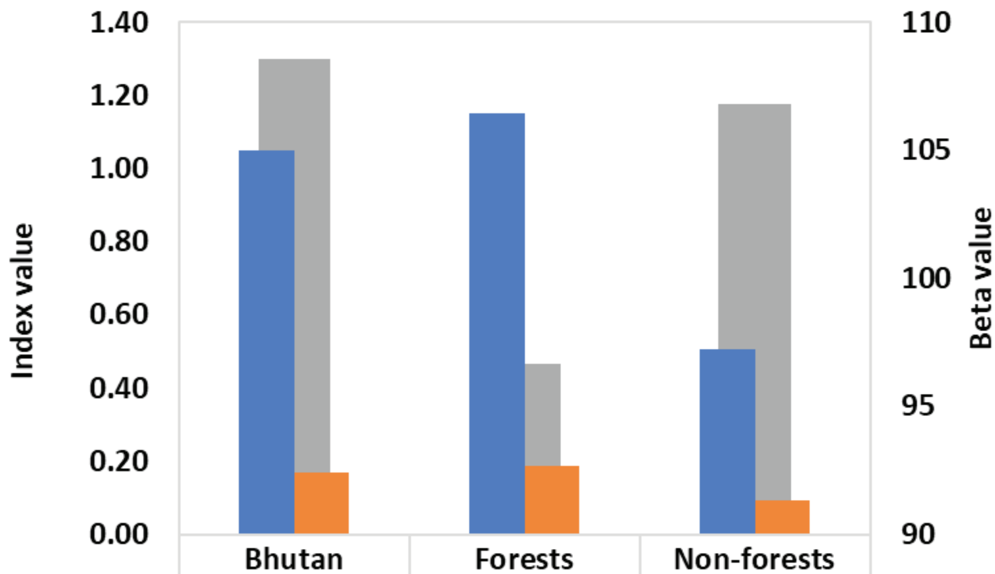


Figure 74: Species accumulation curve for non-forest

The species accumulation curve shows the number of new species recorded for every new sample plot. It is expected that with increasing sample plots accumulation of species will increase and then stabilize. The Figure 73 shows the species accumulation curve in forest land and Figure 74 shows species accumulation curve for non-forest area. This figure shows that the probability of detection of new species is very high with fewer area or sampling sites while the probability is very low as we go on increasing the sample size.

4.2 Species diversity by forest and non-forest area

The diversity of trees varies widely by forest and non-forest area (Figure 75). A total of 448 species (Gamma) were found in the forest area while a total of 250 species were found in the non-forest areas. The diversity indices of Shannon and evenness are 1.15 and 0.19 for forest area and 0.51 and 0.09 for non-forest area respectively (Figure 75). The lower evenness for the non-forest areas shows unequal distribution of species indicating some species dominating the non-forest areas.



	Bhutan	Forests	Non-forests
Beta	109	97	107
Shannon Index	1.05	1.15	0.51
Evenness	0.17	0.19	0.09

Figure 75: Diversity indices of Shannon, Evenness and Beta for the overall Country, forests and non-forest

4.3 Species diversity by Dzongkhag

The tree species mean diversity ranges widely by Dzongkhag (Figure 76). The species diversity (Shannon index) ranges from 0.69 (Thimphu) to 1.53 (Sarpang). The tree species are also more evenly distributed in Sarpang as compared to all other Dzongkhags. Thimphu has the lowest value in the evenness index, indicating uneven distribution of the observed tree species.

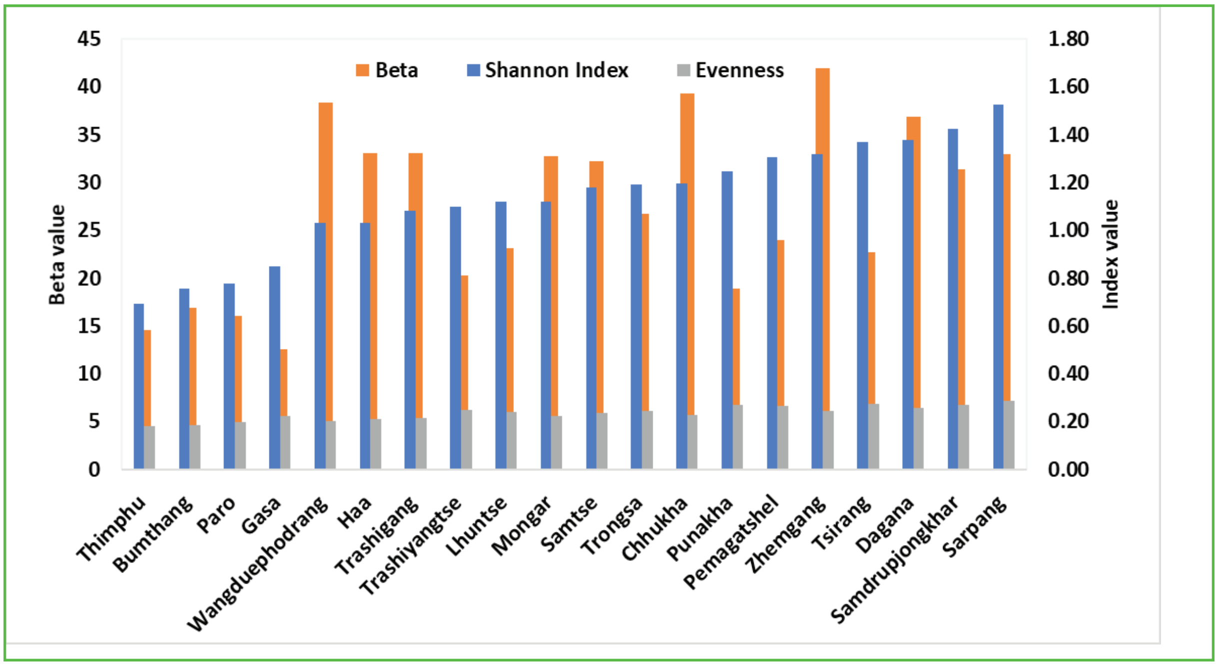
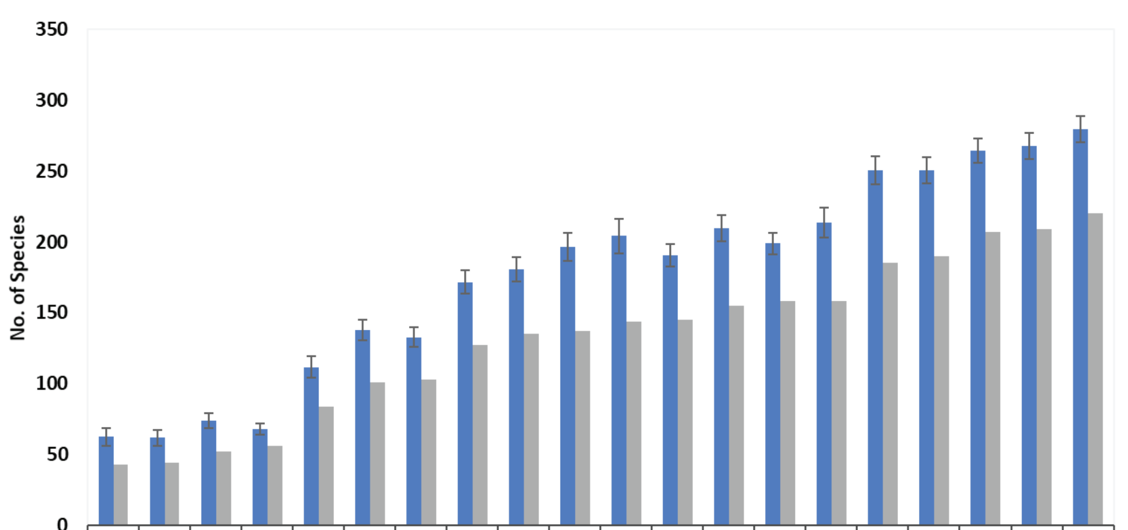


Figure 76: Diversity indices of Shannon, Evenness and Beta by Dzongkhag

However, the number of species observed in each Dzongkhag is greatest in Zhemgang (220) which can go up to 280 species as estimated by the species accumulation model of Jackknife. Gasa Dzongkhag has the lowest species diversity of 43 going up to 63 species (Figure 77). The higher betta diversity of Zhemgang also indicates diverse and unique tree species diversity in the Dzongkhag.



	Gasa	Thm	Paro	Bum	TY	Pun	Lhun	Tro	Pgat	Haa	Tsi	Sam	Mon	Tga	WP	Chhu	SJ	Sar	Dag	Zhm
Extra	63	62	74	68	112	138	133	172	181	197	204	191	210	199	214	251	251	265	268	280
Obs	43	44	52	56	84	101	103	127	135	137	144	145	155	158	158	185	190	207	209	220

Figure 77: Number of observed species and extrapolated species with SE by Dzongkhag

4.4 Species diversity by Forest Type

The species diversity by two major forest types of broadleaf and conifers are presented in Figure 78 and 79. Broadleaf forests constitute about 65 % and conifers about 35 % of the forest area of the country (FRMD, 2017). A total of 426 species were observed in broadleaf forests and 164 species were reported in conifer forests. However, the number of species can go up to 506 (± 9.48) and 227 (± 11.44) species in broadleaf and conifer forest respectively as extrapolated using Jackknife estimate.

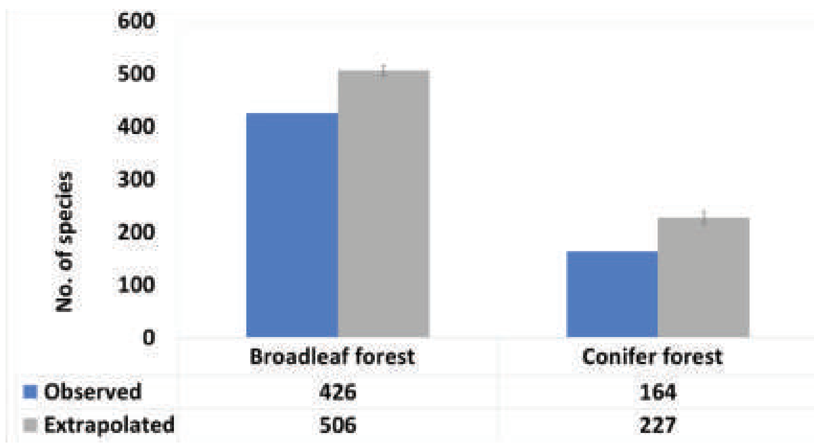


Figure 78: Number of observed and extrapolated species with SE in broadleaf and conifer forest

Though a high number of species has been observed in both broadleaf and conifer forest, the low evenness (0.22 and 0.15 for broadleaf and conifer forest respectively) shows an unequal distribution of species across the country (Figure 78). The mean diversity indices of broadleaf and conifer forests are 1.33 and 0.75 respectively (Figure 78). Higher beta index of broadleaf forests indicates the presence of more unique tree species within the forest type.

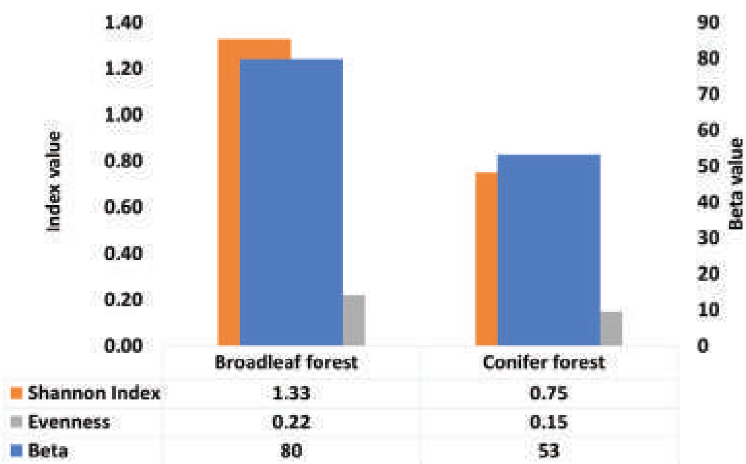
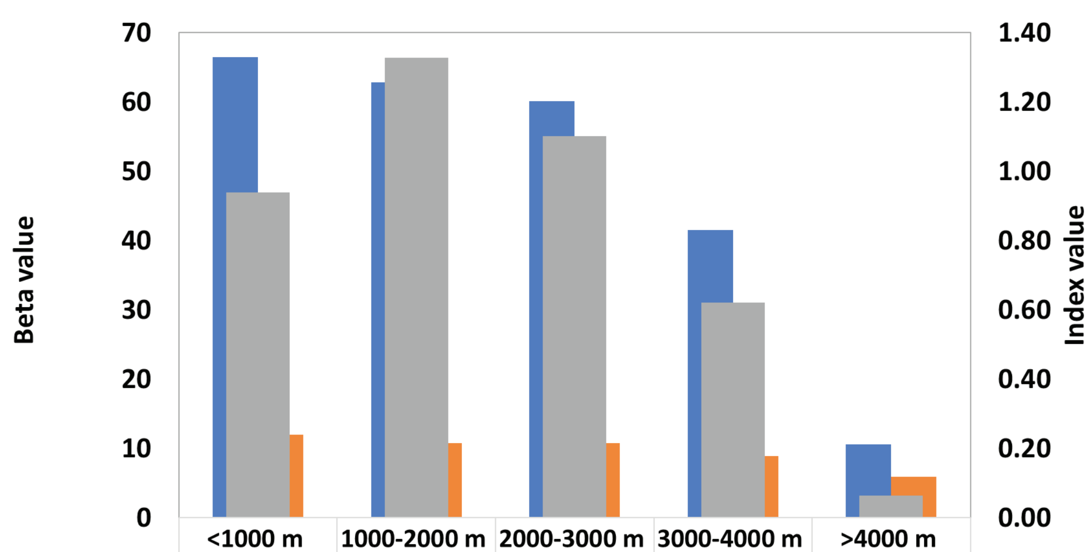


Figure 79: Diversity indices of Shannon, Evenness and Beta in broadleaf and conifer forest

4.5 Species diversity by Elevation

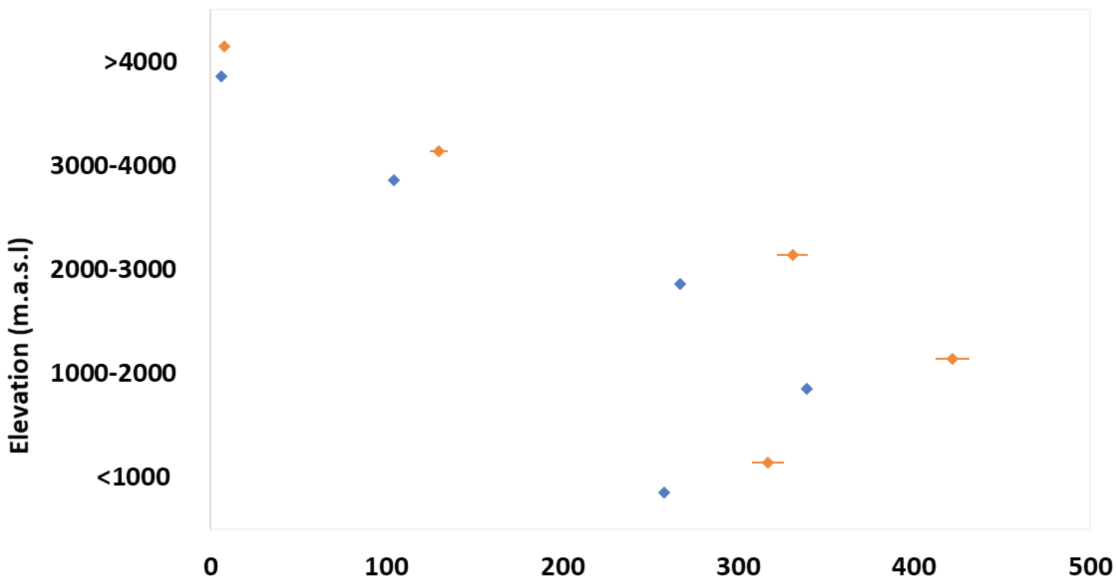
Elevation in Bhutan ranges from 97 m in the southern foothill to more than 7000 min the northern mountains (FRMD, 2017) and is segregated into 11 forest types (FRMD, 2016). The different altitudinal ranges have been further grouped into 5 classes for this study. Greatest number of species (339) has been observed in the elevation range of 1000 to 2000 m(warm broadleaf forest) while only 6 species were observed in the dry alpine scrub above 4000 m(Figure 80).



	<1000 m	1000-2000 m	2000-3000 m	3000-4000 m	>4000 m
Shannon Index	1.33	1.26	1.20	0.83	0.21
Evenness	0.24	0.22	0.22	0.18	0.12
Beta	47	66	55	31	3

Figure 80: Observed and extrapolated number of species with SE by elevation

There are fewer species (258 observed and 317 extrapolated) in the sub-tropical forest (>1000 m) than in the next altitudinal class (1000-2000 and 2000-3000 m). However, the number of species decreases after elevation of 1000-2000 m afterwards (Figure 53). The species diversity ranges from 0.21 to 1.33 and also shows a decreasing trend with an increase in elevation (Figure 81). However, it is important to note that the maximum unknown species were found in the elevation range of 1000 – 2000 m and this could have reduced the species diversity in this elevation range. The evenness show a similar trend with the index decreasing from 0.24 in the sub-tropical forest (<1000 m) to 0.12 in the dry alpine scrub (>4000 m) (Figure 81).



	<1000	1000-2000	2000-3000	3000-4000	>4000
Extrapolated	317	422	331	130	8
Observed	258	339	267	104	6

Number

Figure 81: Diversity indices of Shannon, Evenness and Beta of forests at different elevations

4.6 Discussion

The listing of 463 (538 ± 9) tree species and diversity of 1.05 shows that Bhutan is rich in diversity and can be considered to be among the highly diverse ecosystems in the Himalayan region (Ohsawa, 1987; Singh and Singh, 1987; Ohsawa, 1991, 2002). A study on 20 forest types in India showed a Shannon-Wiener diversity index range between 0.28 and 1.75 (Sharma *et al.*, 2010). Although the mean diversity of 1.05 for Bhutan is within the range of diversities reported in similar ecosystems in the region, it improves when it is analyzed by forest types or by Dzongkhags or by elevations. The diversity values would have been much higher if all the unknown species were identified and taken in consideration. The lower diversity at national level is because it takes in to account non-forest areas (FRMD, 2016) where the tree diversity is very minimal. Non-forest areas includes areas without trees (including water bodies, agriculture land, meadows etc) or with trees less than 5 m in height and/or less than 10% canopy cover (FRMD, 2016). Further the variation in diversity is also due to the existence of unique ecosystems of the moist subtropical (high diversity) in the south to dry alpine scrubs (lower diversity) in the north and the middle dry valleys (lower diversity) in between the humid moist ecosystems. The occurrence of middle dry valleys (parts of Mongar, Punakha and Wangduephodrang) at elevation range of 2500 and in 1000 m, is a unique characteristics of humid eastern Himalayan ranges (Ohsawa, 1987; Wangda and Ohsawa, 2006a).

The trees are more evenly distributed (0.19) when only forests are considered as compared to national level. However, the beta diversity of the non-forests (107) are greater than the forests (97) indicating the more variations (dissimilarity) in the number of species in the non-forest areas (Figure 74). The absence of trees in plots such as water bodies or agriculture field and presence of trees in certain plots have led to the wider variations. This corresponds well with the difference in density of trees in forests (280 trees ha^{-1}) and non-forests (46 trees ha^{-1}) of the National Forest Inventory report volume I (FRMD, 2016). Similarly, Tenzin and Hasenauer (2016) also reported lower number of species in the non-forest areas such as agriculture field as compared to natural forests in broadleaf forests of Dagana. The non-forest areas with lower diversity and tree species provides opportunities for improvement through proper land and forest management for increasing the biodiversity of the area.

The species diversity decreases as the elevation increases, wherein, the sub-tropical and mixed broadleaf forests slowly turn into monoculture or conifer dominated stand and finally to alpine scrub(Wangda and Ohsawa, 2006a). Further, the increase in slope and altitude is characterized by harsher climatic condition especially in the upper range (>4000 m), which results in low species diversity. In the elevation range from 1000 – 3000 m, there is existence of broadleaf and conifer tree species based on the moist and drier site conditions, which further increases diversity and species richness in this elevation range. For instance in the elevation range of 1000 – 2000 m the tree species of *Schima , Lithocarpus and Castanopsis* (broadleaf species) dominates the moist part while on the drier sites tree species of *Quercus* and Chirpine (Conifer) can be observed. Similarly in the elevation range 2000 – 3000, there is broadleaf species up to 2500 m while at the same level Blue pine can also be observed and after 2500 m, the vegetation changes to conifer forests of Hemlock and Spruce (Ohsawa, 1987).

The difference in diversity and species richness between the two forest types explains the diversity in their ecosystems as reported in earlier studies. For instance Moktan *et al.* (2009) reported Shannon diversity indices of 0.9 and 0.86 in mixed conifer forests stands of Haa and Paro while Covey *et al.* (2015) reported Shannon diversity of 2.08 and evenness of 0.47 in an evergreen broadleaf forests of Thimphu, Bhutan. Similarly Tenzin and Hasenauer (2016) reported Shannon diversity of 1.7 and evenness of 0.85 in the broadleaf forests of Dagana. A study on 20 forest types in India showed a Shannon-Wiener diversity index range between 0.28 and 1.75 with higher diversity in deciduous forest as compared to conifer forest (Sharma *et al.*, 2010). Conifer forests are of lower diversity as compared to broadleaf forests because of its mono-specific nature than to the mixed nature stand of the broadleaf forests (Wangda and Ohsawa, 2002; Sharma *et al.*, 2010). Besides, conifer forests in Bhutan are dominated by Blue pine, Chirpine, Spruce, Hemlock, Fir and Junipers whereas broadleaf forests are of multi-storied consisting of numerous dominant and co-dominant species (Ohsawa, 1987; Rosset, 1999). However, the difference in diversity in the two forest types shows the uniqueness of each forest type and this uniqueness provides suitable environment to various flora and faunal species diversity. The forests also provides ecosystem services to the people living in and around the forests and their well-being depends on how well the forests are conserved and managed (Norbu, 2002).

The higher species number and diversity also indicates in which type of forests and elevation the Dzongkhags are located. The land use and land cover of Bhutan (FRMD, 2017) shows Gasa in the conifer zone while Zhemgang and Dagana are in the broadleaf with conifer zone, which explains the lowest species and diversity in Gasa as compared Zhemgang. Further, Zhemgang and Dagana are the two Dzongkhags with the highest forest cover (83 %) as compared to other Dzongkhags of the country (FRMD, 2016). The lower diversity of Thimphu, Paro and Bumthang as compared to similar forest ecosystem of Gasa, indicates the impact of developmental activities to the forests ecosystem. Thimphu, Paro and Bumthang are some of the biggest towns in the country, which are expanding rapidly in size and population. This corresponds well with studies done by Watkins *et al.* (2003) and Tenzin and Hasenauer (2016), which shows that increasing accessibility through road networks upsurges resource extraction and invasive species, thus reducing the species diversity. Tenzin and Hasenauer (2016) suggests proper and regular monitoring of the forests to prevent changes in the forest structure or reduction in diversity due to anthropogenic disturbances.

Elevation encompasses both temperature and humidity which are both decisive in vegetation distribution for a mountainous terrain like Bhutan. The number of species varies along different altitudinal range depending on the physiographic factors, which has a profound influence on the richness and diversity of the forests (Gairola *et al.*, 2011b). The species richness and diversity in most studies worldwide shows peaking of diversity or species composition at intermediate level (for Bhutan range seems to be 1000 – 2000 m) and this point corresponds to the optimal factors which allows co-occurrences of many species (Lomolino, 2001). Similarly Wangda and Ohsawa (2006b) also shows maximum species and species diversity in the mid-elevation transitional forests and in the mixed broad-leaved forests where different life-forms co-existed as compared to extreme conifer forests of Bhutan.

CHAPTER 05
FOREST HEALTH AND DISTURBANCE

Forest disturbances are important factors that affect the structure and composition of a forest. Small scale natural disturbances, such as single-tree blown down, play an important role in maintaining diversity and heterogeneity in forest ecosystem. Such natural disturbances occur as a natural process without the need for management interventions. However, it would be crucial to understand and monitor large scale disturbances, both natural and anthropogenic considering the scale of impact. Both abiotic and biotic disturbances have major impacts on the health and vitality of the world's forests and can result in substantial economic and environmental losses (FAO, 2018).

Ulanova 2000; Chazdon 2003; Hanewinkel et al. 2008; Seidl et al. 2011; Thom & Seidl 2015 cited in Tenzin and Hasenauer (2016), describes natural disturbances consist of wildfires, floods, pest calamities, lightning, wind throw, rock fall, and ungulate browsing while anthropogenic disturbances include activities such as logging, fodder, fuel wood and leaf litter extraction, agriculture clearing, and the introduction of non-native tree species (Bengtsson et al. 2000; Drapeau et al. 2000; Franklin et al. 2000; Chazdon 2003; Lorimer & White 2003; Onain dia et al. 2004; Wangda et al. 2009 as cited in (Tenzin and Hasenauer, 2016).

Through the National Forest Inventory (NFI), qualitative information on presence and absence of few of the disturbance factors have been collected to understand the extent of disturbance and collect a baseline information on the health of our forests. It is hoped that the information generated here would indicate areas for improving the range and method of data collection on forest disturbances for monitoring the health of the forests in Bhutan.
It is to be noted that only those evidence of disturbances recorded on NFI plots are used for spatial representation of distribution of the disturbance indicators. Since the cluster plots are located at a distance of 4km by 4km, the disturbances may not be captured adequately. Additionally, some of evidence, such as for pests and diseases may have been missed or not identified.

5.1 Pests and diseases

The national forest inventory recorded the presence and absence of bark beetle and mistletoe infection as indicators of forest health reported as proportion of infection out of the total enumerated plots and extent of distribution.

Out of 1685 cluster plots, only 23 cluster plots corresponding to 0.014% of total enumerated, have been recorded to be infected with bark beetle. The spatial distribution as seen on Figure 82 shows sporadic infection although found across the length of the country . More than 57% of the bark beetle infection have been recorded in conifer forests with majority observed in fir forests

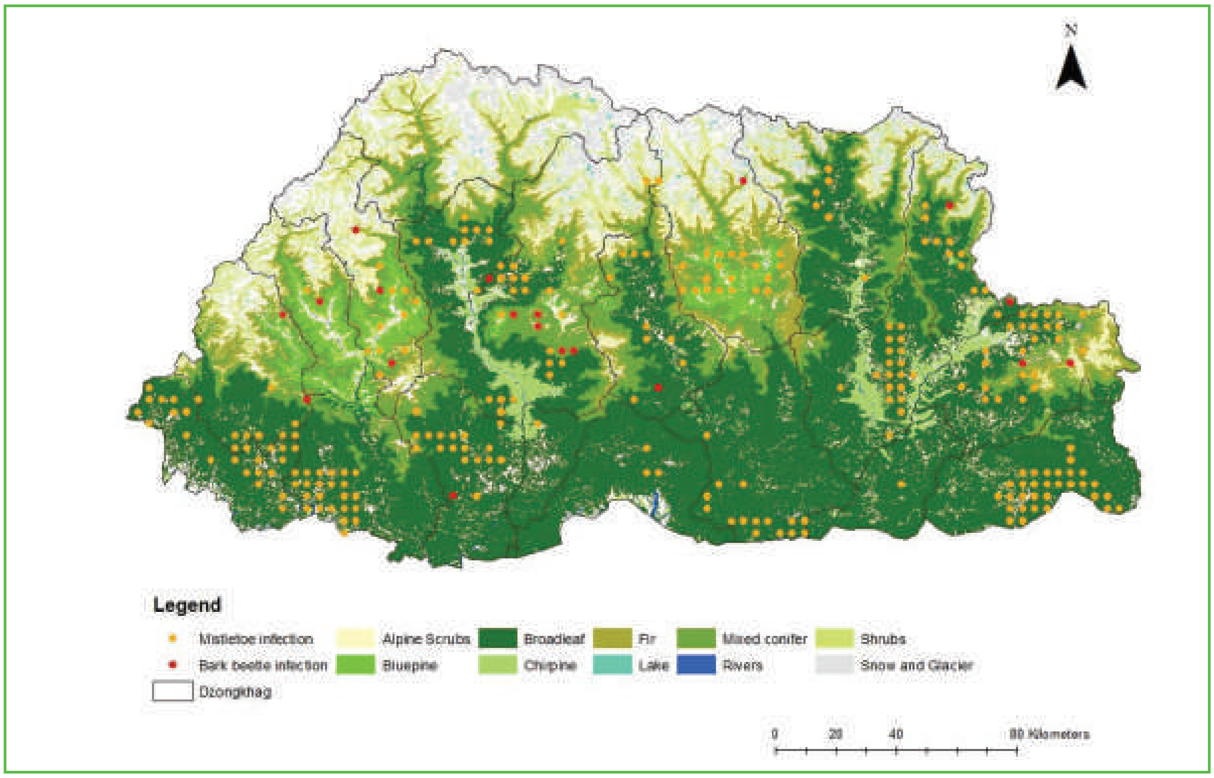


Figure 82: Map showing bark beetle and mistletoe infection recorded on NFI plots

In contrast, mistletoe infection appears to be widely spread and clustered in some of the sites. 253 cluster plots corresponding to 10% of the total enumerated plots are recorded with mistletoe infection. More than 70% of the mistletoe infection are observed in broadleaf forests and rest in conifer forest.

Mistletoes are parasitic plants and considered to be damaging to the trees. However, the severity of damage/impact would depend on the species infecting the tree. Mistletoes such as Himalayan dwarf mistletoe (*Arceuthobium minutissimum*) and Leafy mistletoe (*Taxillus kaempferi)* have been studied and reported to infect blue pine, hemlock and spruce (Dorji *et al.*, 2012). Dwarf mistletoes are known to cause "deformations, stunted growth, systemic witches broom, strong reduction of diameter and height growth, impaired wood quality ,reduced cone production and mortality (Hawksworth et al., 1996; Dorji, 2007 as reported in Dorji *et al.* (2012)" while Leafy mistletoes causes weakening of trees. Because of its severe impact on the host tree *A. minutissimum* is the most important pathogen of P. wallichiana in Bhutan. Even where insect pests and microbial pathogens are considered, it is most probably still the most important biotic damaging factor on this conifer species (Dorji *et al.*, 2012). There are not many studies on mistletoe infection on broadleaf species in Bhutan.

Considering the spatial distribution and clustering of mistletoe infection, it may be inferred that there is comparatively higher severity of risk from mistletoe infection than by bark beetle infection.

5.2 Timber Harvesting

Timber extraction is an important anthropogenic disturbance factor that affects the stand dynamics and resulting species composition. Through the national forest inventory, the presence absence of timber extraction within the plot was collected to assess the extent of such disturbance in our forests.

A total of 349 cluster plots showed evidence of timber harvesting out of which almost 80% of the extraction was recorded as selective felling and less than 1 percent to show clear felling of trees. Figure 83 shows the spatial distribution of the recorded evidence of timber extraction which is observed to be clustered near human settlements and road networks. About 20% of the enumerated plots suggests "semi-disturbed" (Tenzin and Hasenauer, 2016) conditions.

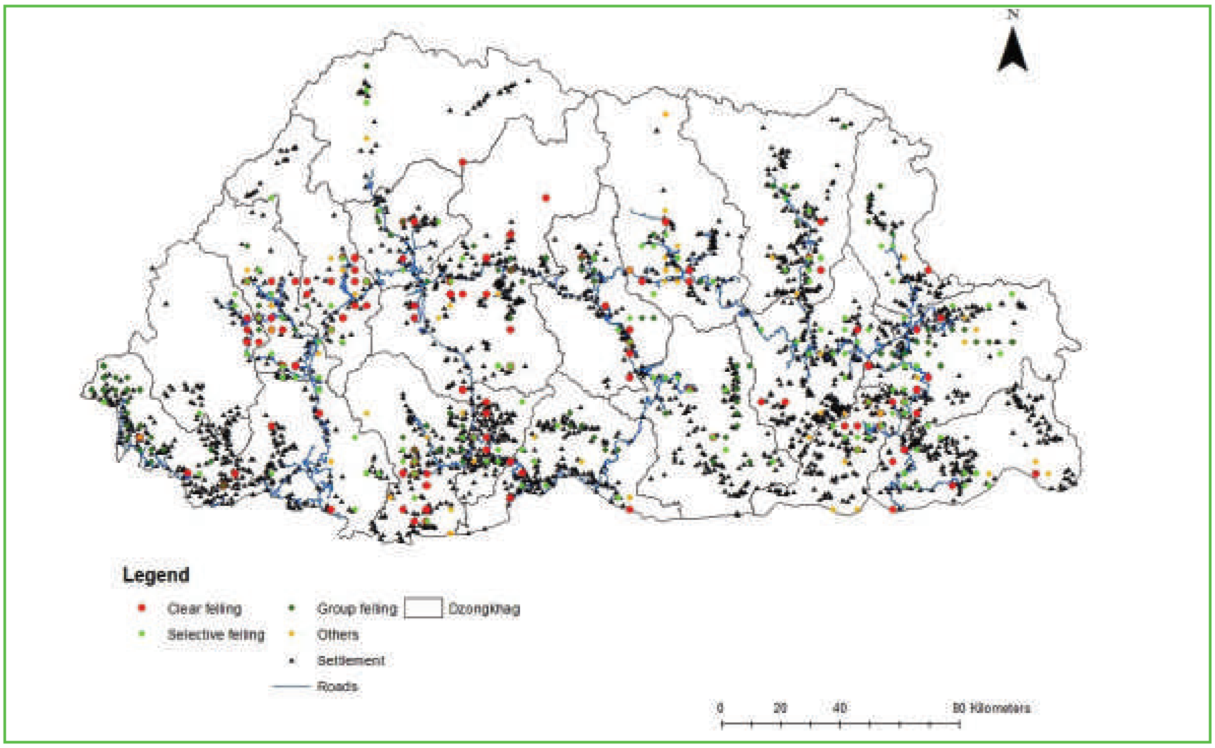


Figure 83: Timber extraction recorded by NFI

5.3 Grazing

Livestock grazing is considered to be human-induced factor that affects natural regeneration of forests trees, including the establishment and stability of seedlings (Oliver et.al, 1996, Barman et.al, 1979 as reported in Pour et.al, 2012). Matsumoto et.al (1999) showed that severe grazing in Japan reduced sapling density and damaged tree growth (Pour et.al,2012).

National forest inventory data suggests extensive disturbance from grazing(Figure 84). 54% of the enumerated plots show evidence of grazing, which includes both direct evidence (presence of livestock) and indirect evidence (dungs, browsing evidence). While the spatial distribution suggests higher association/correlation of grazing to closeness to human settlements, significant number of plots away from settlements is also observed to show evidence of grazing.

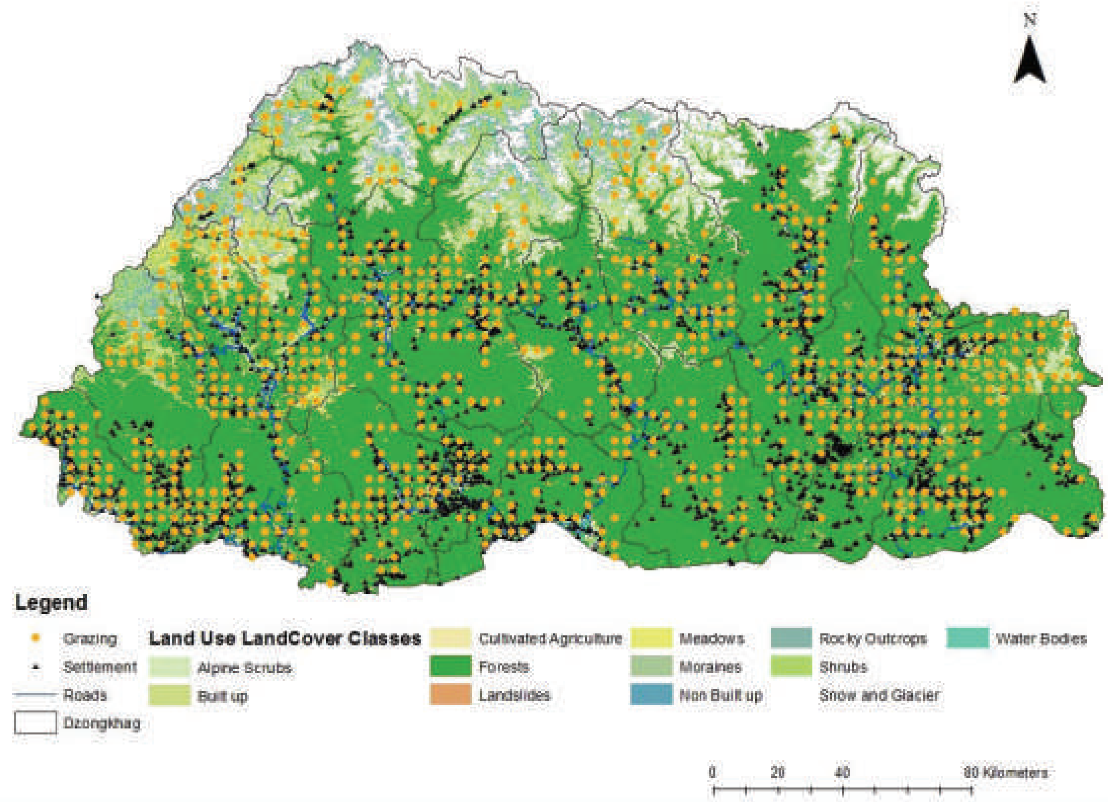


Figure 84: Grazing evidence recorded by NFI

5.4 Garbage /waste

Garbage and waste disposal is a growing concern in Bhutan, especially in the towns and cities. NFI recorded the presence of garbage or waste products to determine the extent of problem in forests as well. A total of 127 cluster plots corresponding to 0.07% of the enumerated plots showed evidence of garbage/waste products categorized into food wrappers, PET bottles, construction dumps and mixture of all(Figure 85). Garbage/waste evidence is also observed to be found mostly in forest near settlements or in close proximity to roads.

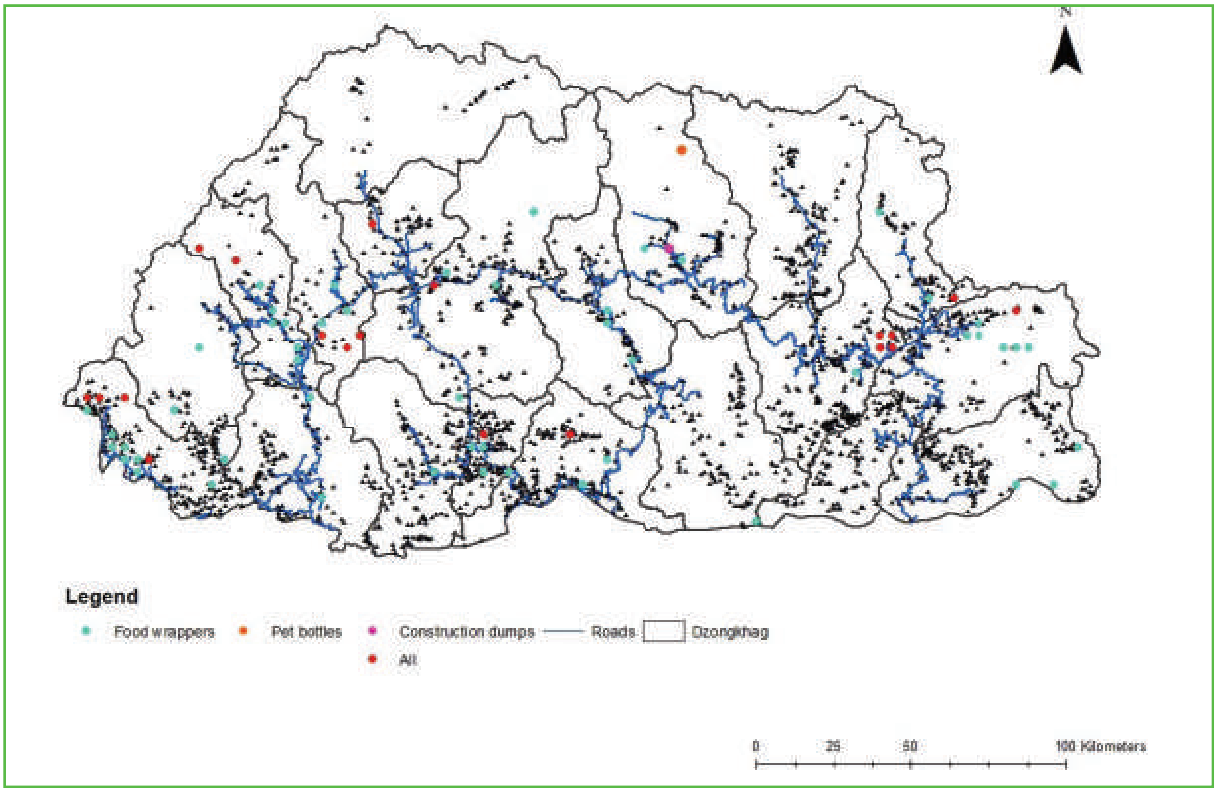


Figure 85: Evidence of garbage and waste materials recorded by NFI

5.5 Discussion

Among the disturbance categories, grazing forms the greatest disturbance factor based on proportional distribution of positive evidence. 54 % of the enumerated plots show evidence of grazing which spread beyond the vicinity of settlements. Timber harvesting is observed in 20% of the enumerated plots and found closely associated with human settlements as also observed by Tenzin and Hasenauer (2016).

Mistletoe infection ranked the third greatest disturbance factor with 10% of the enumerated plots showing evidence of infection. However, in terms of impact, the mistletoe infection would have greater negative impact on forests if not addressed with appropriate management interventions. It can also result in weakened stand, susceptible to infection from bark beetles and forest fire.


@Ngawang Gyeltshen, NCD, DoFPS

CHAPTER 06

NON-WOOD FOREST PRODUCE

Non Wood Forest Produce which can be defined as goods and services derived from forest other than timber. In our context, NWPF shall include wild vegetable, cans, bamboos, fruits, herbs, spices, mushrooms, nuts, brooms, medicinal and aromatic plants, edible mushrooms, etc. Globally, several millions of people depend heavily on NWFP for subsistence and/or income generation.

On account of the social and economic developments, the management and marketing of the NWFPs are becoming more important for their management as well as marketing. The utilization and management of NWPF has gained popularity in Bhutan and about 136 l NWFP management groups are operational across the country for management and marketing of canes, bamboos, mushrooms, piper, amla, zanthoxylum, *Paris Polyphylla, Terminalia, swertia, Rubia* and some medicinal plants. The distribution of bamboos, canes and medicinal plants are reported here to supplement the information on their spatial distribution in Bhutan based on data collected from NFI plots.

6.1 Bamboos

Bamboos are very important non-wood forest product with significant economic importance globally. There are 30 species (Stapleton, 1994 as cited in Moktan et al., 2007) and 13 genus of bamboo in Bhutan (Noltie, 2000). NFI has recored 12 genus of bamboos during field survey . The bamboos were recorded in 806 plots, 18 bamboo were identified up to species level in 342 plots while bamboo in 386 locations were identified up to genus level. Bamboo recorded in 78 locations were remained unidentified. The *Bambusa* and *Dendrocalamus* species were mostly recorded in lower elevation ranges while *Borinda grossa* and *Yushania* species were recorded up to 3700 to 3900 m. Table 8 shows the list of bamboos recorded during NFI and the spatial distribution of the bamboos recorded during NFI field survey is given in Figure 86 .

Table 8: List of bamboo species recorded through NFI

Sl. No	Name	Family
1	*Ampelocalamus patellaris*	Poaceae
2	*Ampelocalamus sp.*	Poaceae
3	*Arundinaria racemosa*	Poaceae
4	*Bambusa alamii*	Poaceae
5	*Bambusa balcooa*	Poaceae
6	*Bambusa clavata*	Poaceae

7	*Bambusa nutans*	Poaceae
8	*Bambusa sp.*	Poaceae
9	*Borinda grossa*	Poaceae
10	*Cephalostachyum latifolium*	Poaceae
11	*Chimonobambusa callosa*	Poaceae
12	*Chimonobambusa sp.*	Poaceae
13	*Dendrocalamus giganteus*	Poaceae
14	*Dendrocalamus hamiltonii*	Poaceae
15	*Dendrocalamus hookeri*	Poaceae
16	*Dendrocalamus sp.*	Poaceae
17	*Drepanostachyum sp.*	Poaceae
18	*Drepanostachyum intermedium*	Poaceae
19	*Himalayacalamus sp.*	Poaceae
20	*Neomicrocalamus andropogonifolius*	Poaceae
21	*Neomicrocalamus sp.*	Poaceae
22	*Thamnocalamus spathiflorus*	Poaceae
23	*Yushania hirsuta*	Poaceae
24	*Yushania maling*	Poaceae
25	*Yushania microphylla*	Poaceae
26	*Yushania sp.*	Poaceae
27	*Unknown (78 location)*	

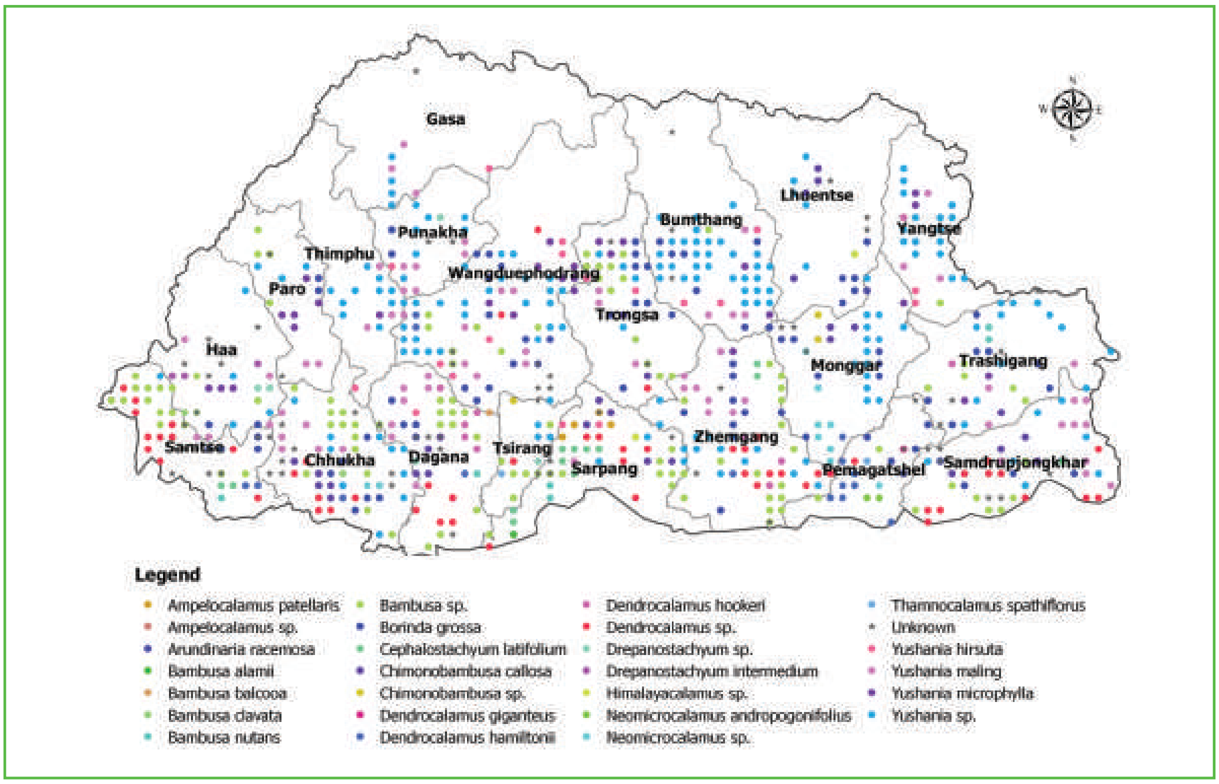


Figure 86: Location of bamboos recorded by NFI

6.2 Canes

Canes are very important NWFP in Bhutan and used for many purposes including roofing, fence construction, basket-making, handicraft items and for a range of tying and stitching purposes (Stapleton *et al.*, 1997; Moktan *et al.*, 2007). There are 10 species of canes found in Bhutan, which are generally found in warmer climatic regions (Stapleton *et al.*, 1997; Moktan *et al.*, 2007).

The NFI field work has recorded the presence of canes in Bhutan and spatial observation of canes is shown in Figure 87.

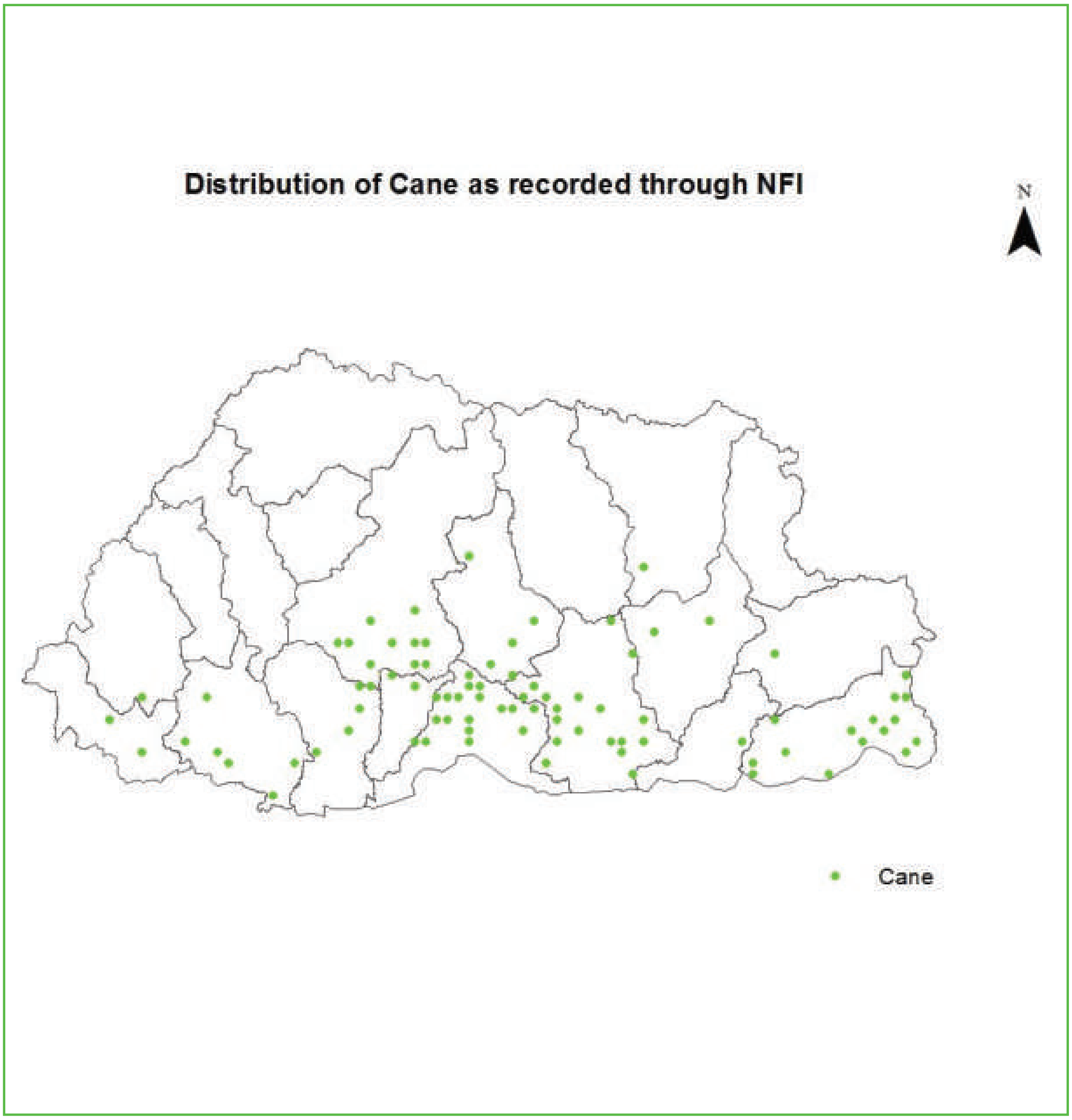


Figure 87: Spatial distribution of canes as recorded by NFI

6.3 Medicinal plants

A total of 76 medicinal plants have been recorded through NFI. 16 are identified as trees, 27 as shrubs and 42 as herbs. The medicinal trees are distributed amongst 933 cluster plots (Table 9), shrubs among 558 cluster plots (Table 10) and herbs amongst 148 cluster plots (Table 11).

It is observed that medicinal herbs and shrubs are mostly been recorded in higher elevation ranges while the trees are recorded below 4000 m elevation (Figure 88).

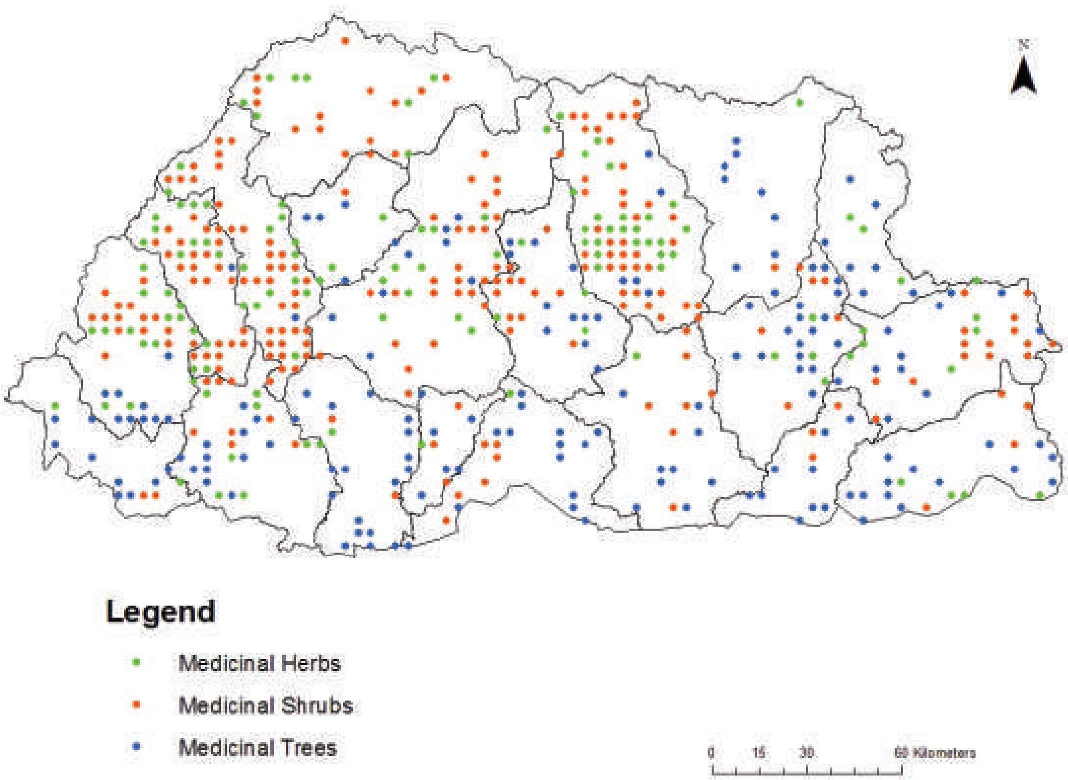


Figure 88: Distribution of medicinal plants by its plant form.

Table 9 : List of medicinal trees recorded through NFI with total number of cluster plots with positive observation

Sl.No	Trees of medicinal value recorded	Number of cluster plots with positive observation
1	*Acacia catechu*	5
2	*Bombax ceiba*	35
3	*Calotropis gigantea*	2
4	*Cassia fistula*	7
5	*Cinnamomum tamala*	149
6	*Erythrina arborescens*	16
7	*Erythrina stricta*	48
8	*Juniperus pseudosabina*	1
9	*Juniperus recurva*	304
10	*Juniperus squamata*	107
11	*Phyllanthus emblica*	23
12	*Rhus chinensis*	78
13	*Taxus baccata*	108
14	*Terminalia bellirica*	29
15	*Terminalia chebula*	16
16	*Zanthoxylum armatum*	4
	Total record of cluster plots	**932**

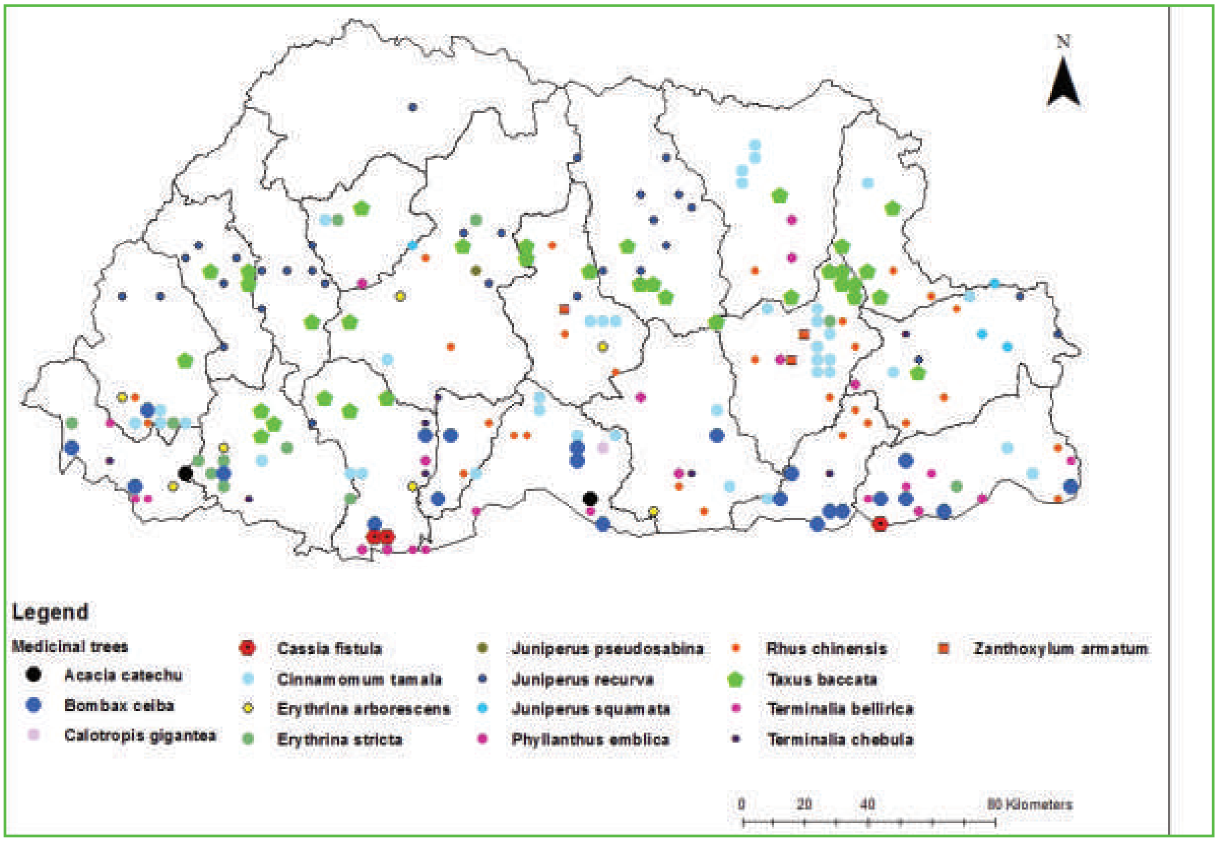


Figure 89: Distribution of medicinal trees recorded through NFI

Table 10: List of medicinal shrubs recorded through NFI with total number of cluster plots with positive observation

Sl.No	Shrubs of medicinal value recorded	Number of cluster plots with positive observation
1	*Acorus calamus*	2
2	*Berberis aristata*	4
3	*Cirsium verutum*	1
4	*Clematis acutangula*	1
5	*Cotoneaster microphyllus*	48
6	*Cymbopogon flexuosus*	1
7	*Elsholtzia eriostachya*	2
8	*Euphorbia griffithii*	2
9	*Fragaria nubicola*	1
10	*Hedychium spicatum*	1
11	*Juniperus recurva*	4
12	*Juniperus squamata*	4
13	*Phyllanthus emblica*	10
14	*Piper longum*	7
15	*Piper pedicellatum*	5
16	*Punica granatum*	1
17	*Rheum nobile*	1
18	*Rhododendron anthopogon*	98
19	*Rhododendron glaucophyllum*	1
20	*Rhododendron setosum*	94
21	*Rhus chinensis*	2
22	*Ricinus communis*	1
23	*Rosa macrophylla*	88
24	*Rosa sericea*	167
25	*Rubia cordifolia*	1
26	*Sambucus adnata*	9
27	*Spiraea arcuata*	2
	Total record of cluster plots	**558**

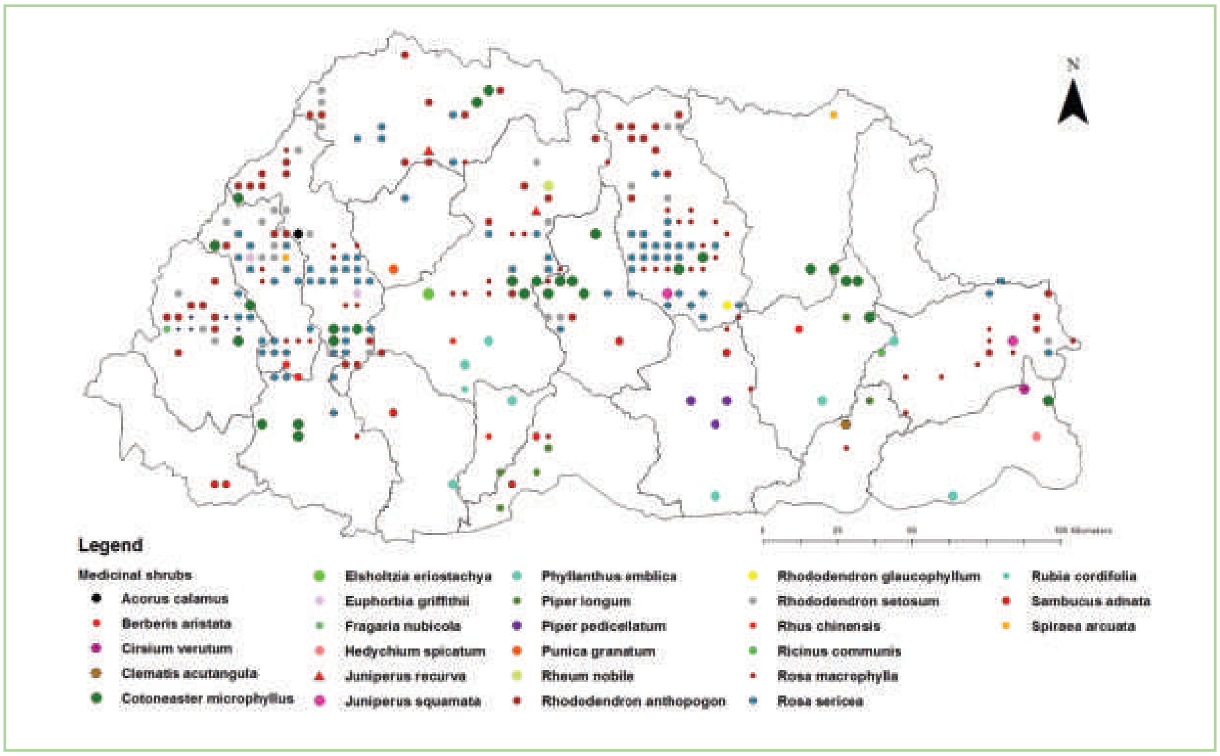


Figure 90: Distribution of medicinal shrubs recorded through NFI

Table 11: List of medicinal herbs recorded through NFI with total number of cluster plots with positive observation

Sl.No	Shrubs of medicinal value recorded	Number of cluster plots with positive observation
1	*Acorus calamus*	1
2	*Anaphalis contorta*	1
3	*Anemone rivularis*	3
4	*Arisaema jacquemontii*	1
5	*Astilbe rivularis*	2
6	*Bistorta macrophylla*	1
7	*Cirsium verutum*	1
8	*Cymbopogon flexuosus*	13
9	*Drosera peltata*	4
10	*Elettaria cardamomum*	1
11	*Euphorbia griffithii*	1
12	*Fragaria nubicola*	22
13	*Galium aparine*	1
14	*Gentiana urnula*	1
15	*Geranium procurrens*	1
16	*Hedychium spicatum*	1
17	*Hemiphragma heterophyllum*	7
18	*Iris kemaonensis*	1
19	*Ligularia amplexicaulis*	1
20	*Malva verticillata*	1
21	*Meconopsis paniculata*	3

22	*Panax pseudoginseng*	1
23	*Paris polyphylla*	4
24	*Pedicularis megalantha*	1
25	*Phlomis rotata*	1
26	*Phyllanthus emblica*	1
27	*Piper longum*	3
28	*Plantago depressa*	1
29	*Potentilla arbuscula*	1
30	*Primula sikkimensis*	4
31	*Primula sp.*	39
32	*Pterocephalus hookeri*	1
33	*Rheum australe*	3
34	*Rheum nobile*	5
35	*Rhododendron setosum*	1
36	*Rubia cordifolia*	4
37	*Salvia castanea*	1
38	*Sambucus adnata*	1
39	*Saussurea gossypiphora*	1
40	*Selinum wallichianum*	5
41	*Senecio chrysanthemoides*	1
42	*Swertia chirayata*	1
	Total record of cluster plots	**148**

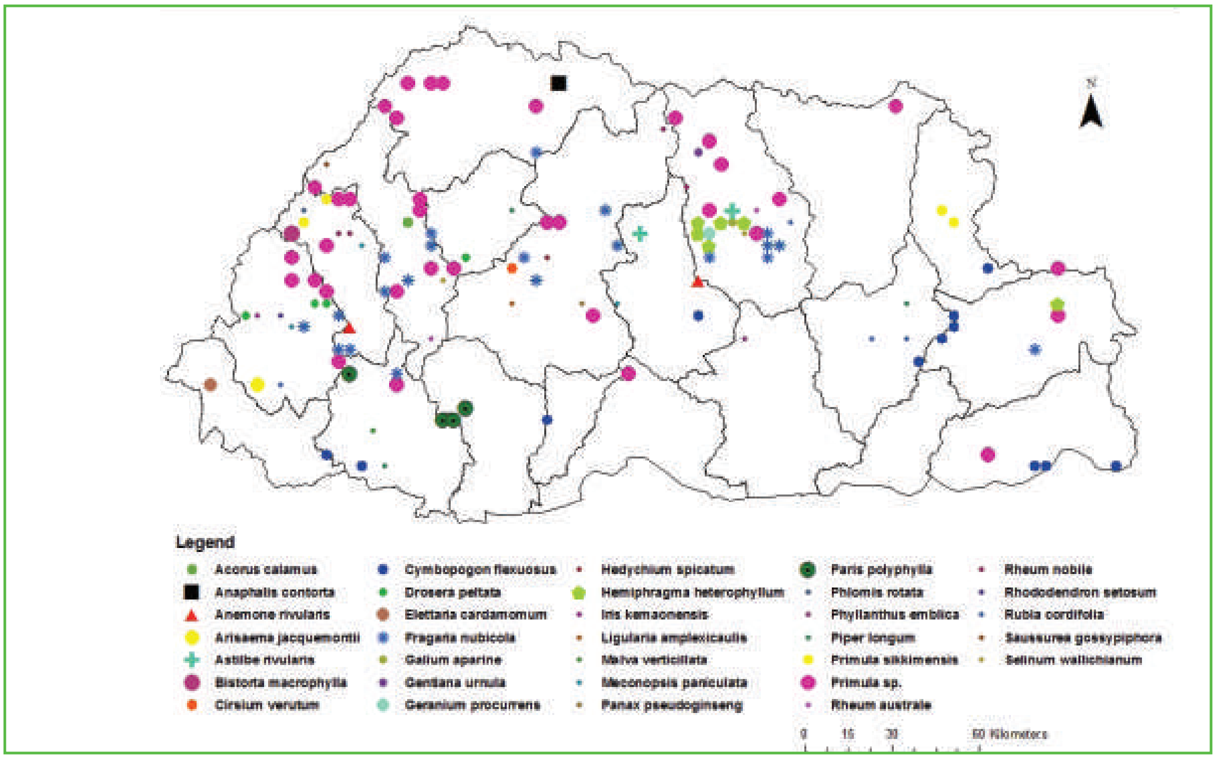


Figure 91: Distribution of medicinal herbs recorded through NFI

CHAPTER 07

WILDLIFE

7.1 Methodology

NFI wildlife data were collected for one time (on a single visit to the cluster plots) and contains information from spatial replication but no temporal replication data is available. Of the 2424 cluster plots, wildlife data were collected in 1685 plots. The remaining 739 plots which were inaccessible are reported as missing information in this analysis.

There are different analytical methods available to analyze presence-absence data (or occurrence only data). The classical approach to analyzing the presence-only data using the maximum likelihood logistic regression, implemented under generalized linear modeling (GLM) framework was used (Guisan *et al.*, 2002). In this framework, the occurrence (or presence only) data as well as data from the plots where species was not observed and the plots which were inaccessible due to terrain or weather were used. Absence data provides information on unsurveyed plots and prevalence of species given survey effort.

In GLMs, a set of predictor variables X_j are combined to produce a linear predictor (LP) to get the expected response value $\mu = E(Y)$ of a variable Y through link function g() as,

$$g(E(Y)) = LP = \alpha + \beta X^T$$

where the expression on the left denotes response variable, α is the intercept, β is the vector of regression coefficients and X is the vector of predictor variables (following Guisan et al., 2002). The general expression for i^{th} observation is represented as,

$$g(\mu_i) = \alpha + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots.. + \beta_n x_{in}$$

For prediction mapping we used the raster files of predictor variables (x_{in}) and beta coefficients (α and β) in the above equation. The logit link formulation with binomial distribution was specified in the final model.

Binomial data ('1' indicating animal and/or indirect evidence observed in one of the cluster plots (refer to NFI Volume I for cluster plot design) and '0' indicating no animal and/or sign observed) with missing information (inaccessible plots) were constructed for each mammal species. The prediction mapping of distribution were performed for those animals which were observed in more than or equal to 100 cluster plots.

Covariates used as predictor variables were forest cover (from global forest change layer (GFC) (Hansen *et al.*, 2013), elevation (shuttle radar topography mission (SRTM; (USGS, 2016))), slope, distance to major rivers, distance to road and distance to settlement. All the covariates were standardized to the mean of zero and unit standard deviation for computational efficiency. For the convenience of mapping all the raster files were generated at 90 m resolution. The dredging method was avoided and the models were only constructed that exhibited biological sense. AIC was used for model selection (Burnham and Anderson, 2004).

7.2 Results

The predicted distribution maps of large mammals in Bhutan are shown below. These maps only depict *apparent* distribution because of the use of presence only records.

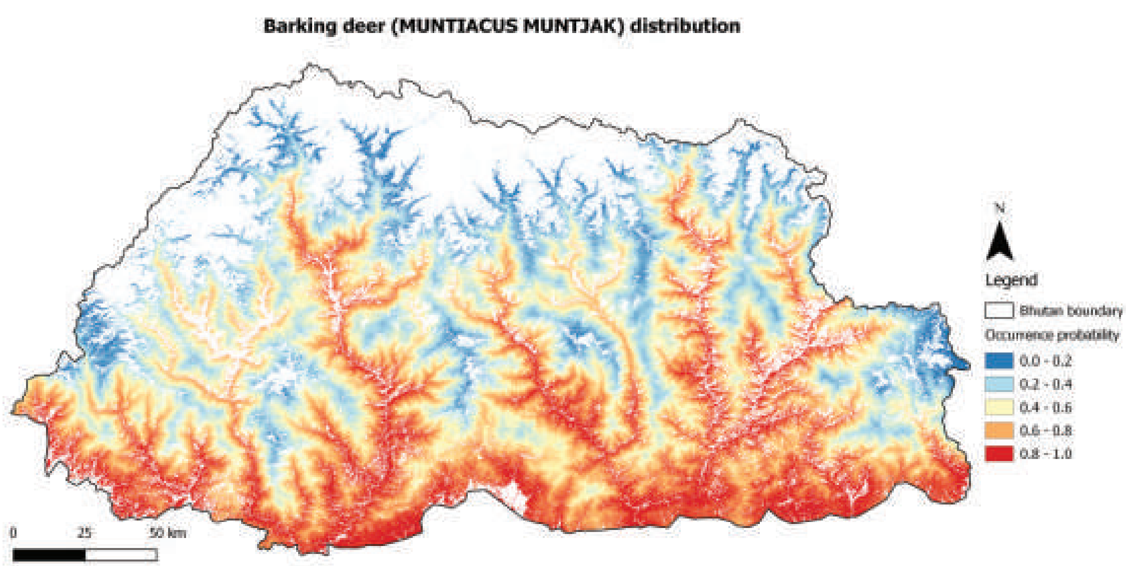


Figure 92: Predicted distribution of barking deer in Bhutan

Barking deer was recorded throughout the country (Figure 92). The elevation ranges between 100m and 4000m. Forested habitat was mostly selected but were also found at the edge of forest-settlement interface.

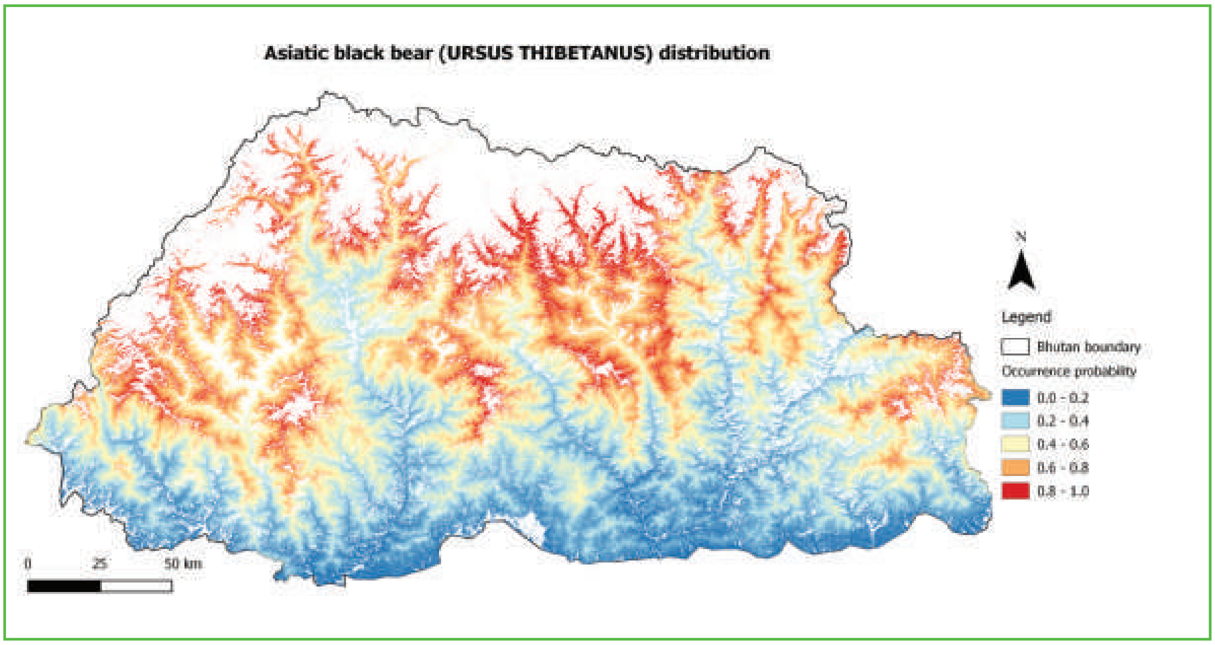


Figure 93: Predicted distribution of Asiatic black bear in Bhutan

Asiatic black bears are mostly found at higher altitudes (Figure 93). Bears mostly avoided habitat close to settlement. However, there are few incidences of bears straying close to human habitation.

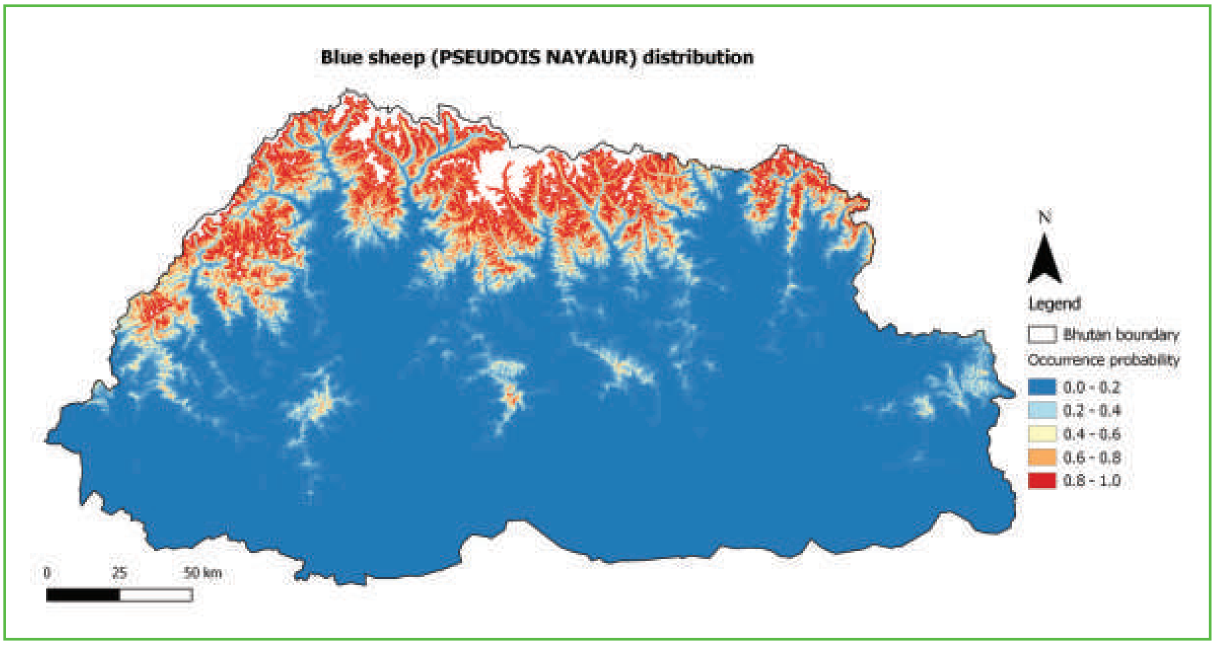


Figure 94: Predicted distribution of blue sheep in Bhutan

Blue sheeps were found at higher altitude. IUCN record shows the elevation range between 2500m and 5500m. Our findings are in congruence with national snow leopard survey report which showed that blue sheep were mostly found in alpine meadow (Thinley *et al.*, 2016). The distribution (Figure 94) overlaps with snow leopard distribution thus indicating the principle prey for the later (Thinley *et al.*, 2016).

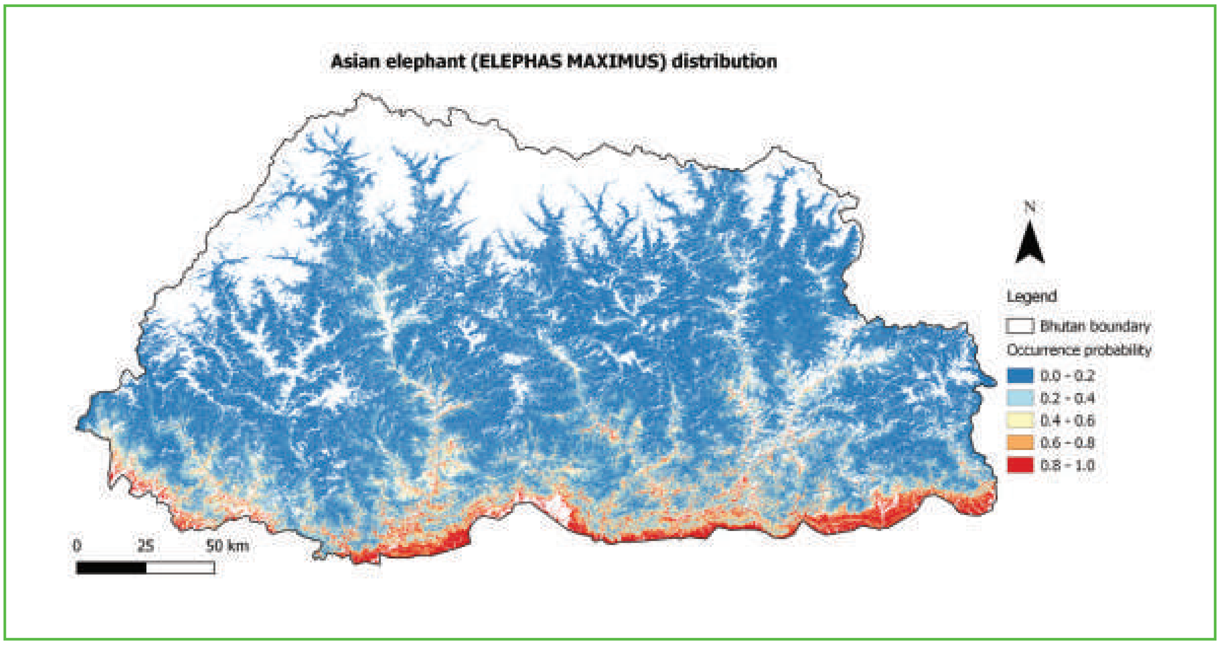


Figure 95: Predicted distribution of Asian elephant in Bhutan

Asian elephants are mostly confined to the southern foothills of Bhutan(Figure 95). High probability of occurrence was depicted in Phipsoo Wildlife Sanctuary, Royal Manas National Park, Jomotshangkha Wildlife Sanctuary, Samdrupjongkhar and Samtse. Gedu reported few lone males during the field observation. The elephant population found in Bhutan shares habitat with Indian protected forests and reserves (NCD, 2018 unpublished data). The national elephant survey preliminary analysis shows that elephants selected forest habitat in the lower altitude.

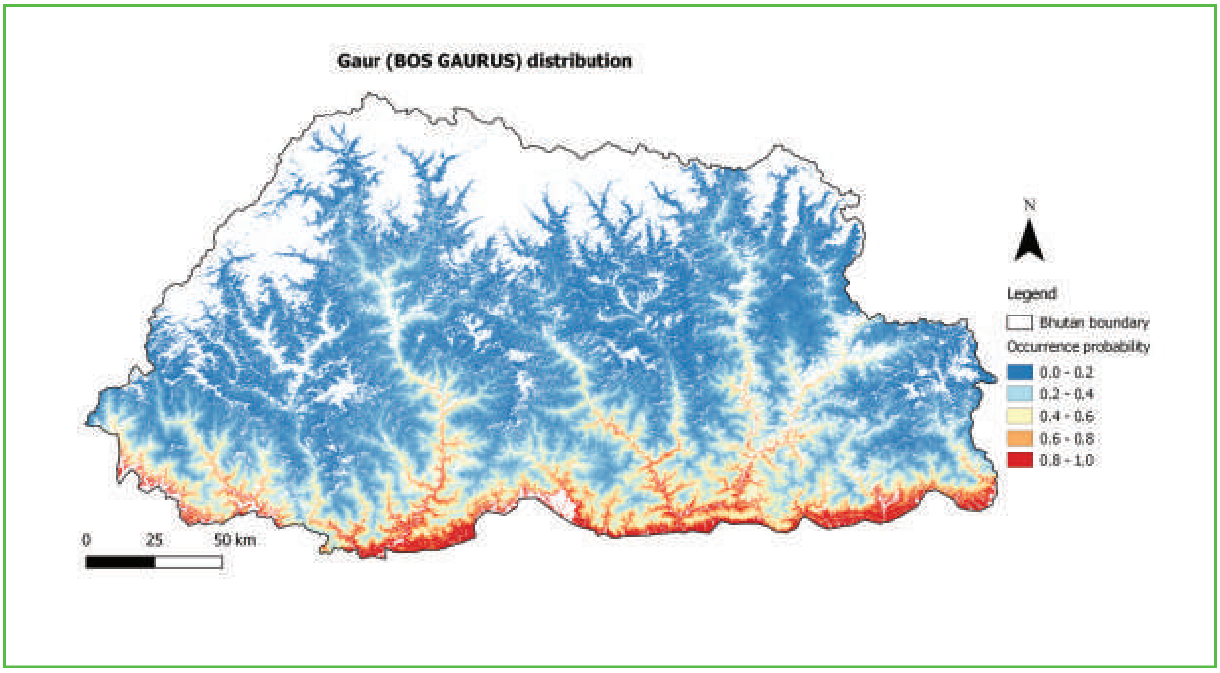


Figure 96: Predicted distribution of gaur in Bhutan

Gaurs were also found in the southern foothills (Figure 96). However, there is evidence of gaur recorded at higher altitude (upto 2500m). Gaur is the main prey for larger carnivore species such as tiger and leopard (Karanth, 2001). Our analysis reveals that gaur shares habitat with elephants. This implies that lower foothills of Bhutan are important habitat for megaherbivore conservation.

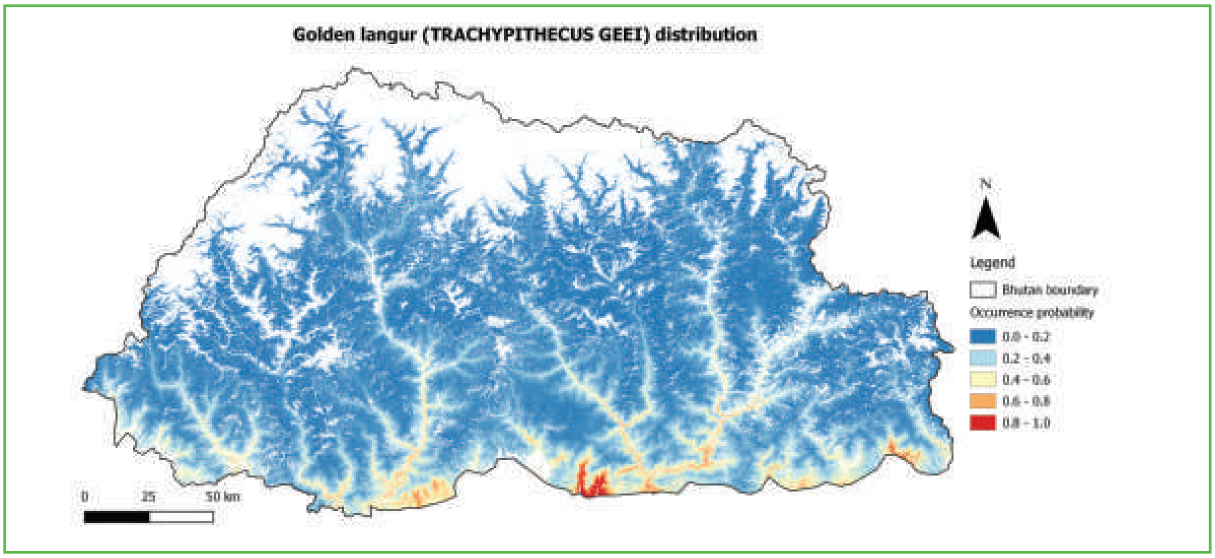


Figure 97: Predicted distribution of golden langur in Bhutan

Golden langurs were found between Punatshagchhu and Mangdechhu rivers(Figure 97). High occurrences are reported in PWS and RMNP but are also found in lower banks of Drangmech-hu. Recent golden langur survey also showed that they are found in almost all geogs (sub block of district administration) of Tsirang. This means that, as opposed to traditional belief, golden langurs are found in potential habitat beyond Punatshangchhu and Mangdechhu.

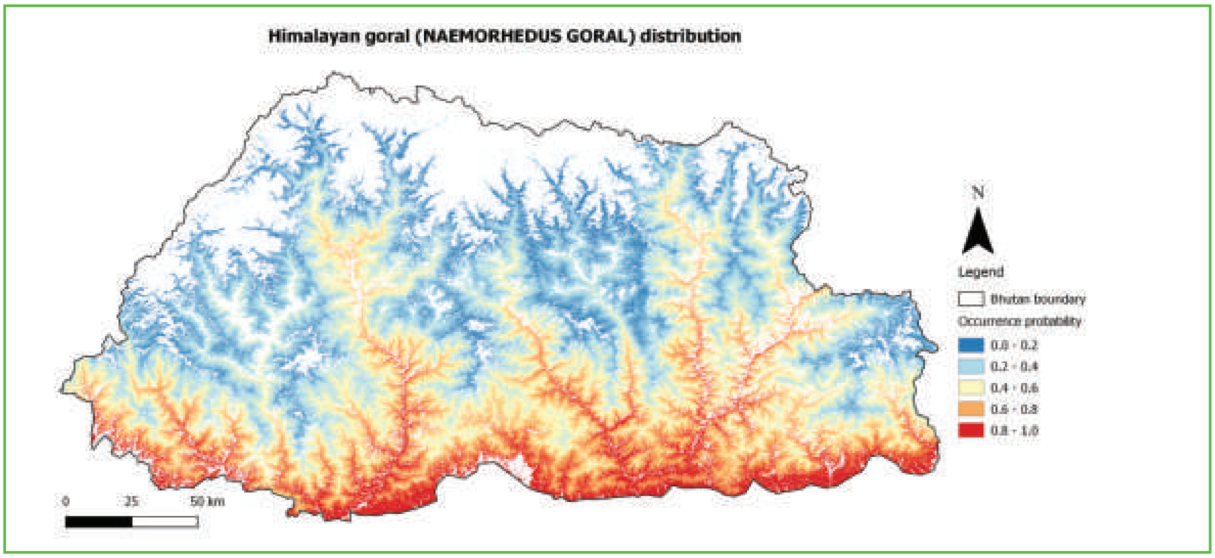


Figure 98: Predicted distribution of Himalayan goral in Bhutan

Goral was recorded below the altitude of 3000m (Figure 98). The potential distribution overlaps with barking deer. This may be due to misidentification of indirect evidence of the barking deer as goral or vice versa. Gorals are small ungulates inhabiting forested and rugged terrain. The records in NFI data included direct sighting, dung pellets and call records.

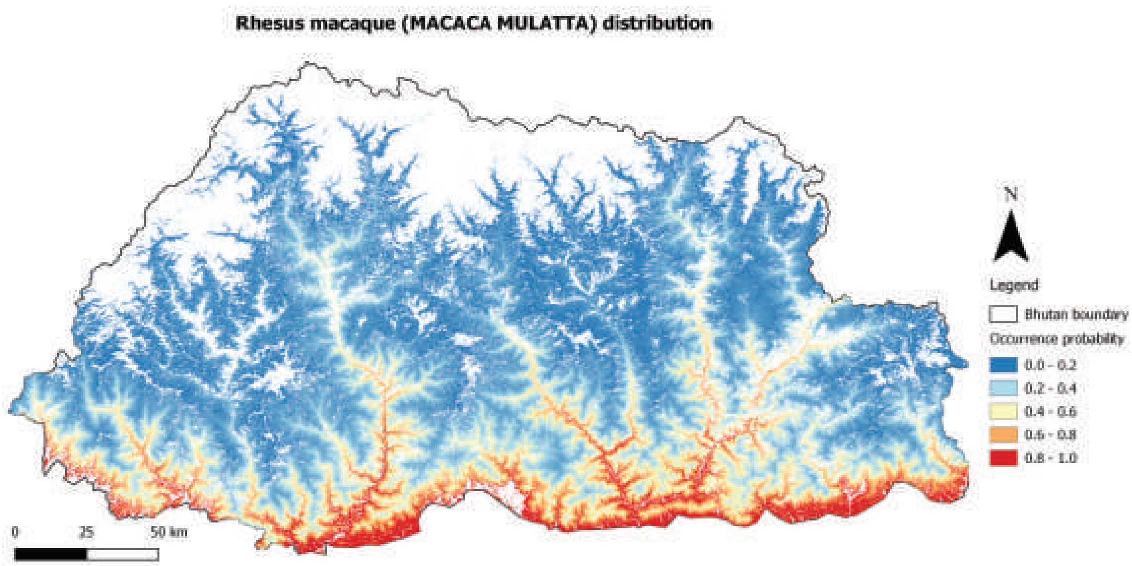


Figure 99: Predicted distribution of Rhesus macaque in Bhutan

Rhesus macaques' probability of occurrence was highest in the lower altitude and were mostly distributed in the southern districts (Figure 99). However, there are also records of macaques in the temperate zone. Macaques are found along the highways. The reason behind such behavior is unknown. The display of such behaviors to moving vehicles and humans is presumed acquired. Commuters feed them and this might have conditioned them to dwell on the road for easy feeding. There is also a high risk of death from collision and one of the reasons of conflict. There exisit a possible discrepancy in identification of Rhesus and Assamese macaque, so the true distribution of Rhesus macaques is highly questionable due to misidentification and false positives.

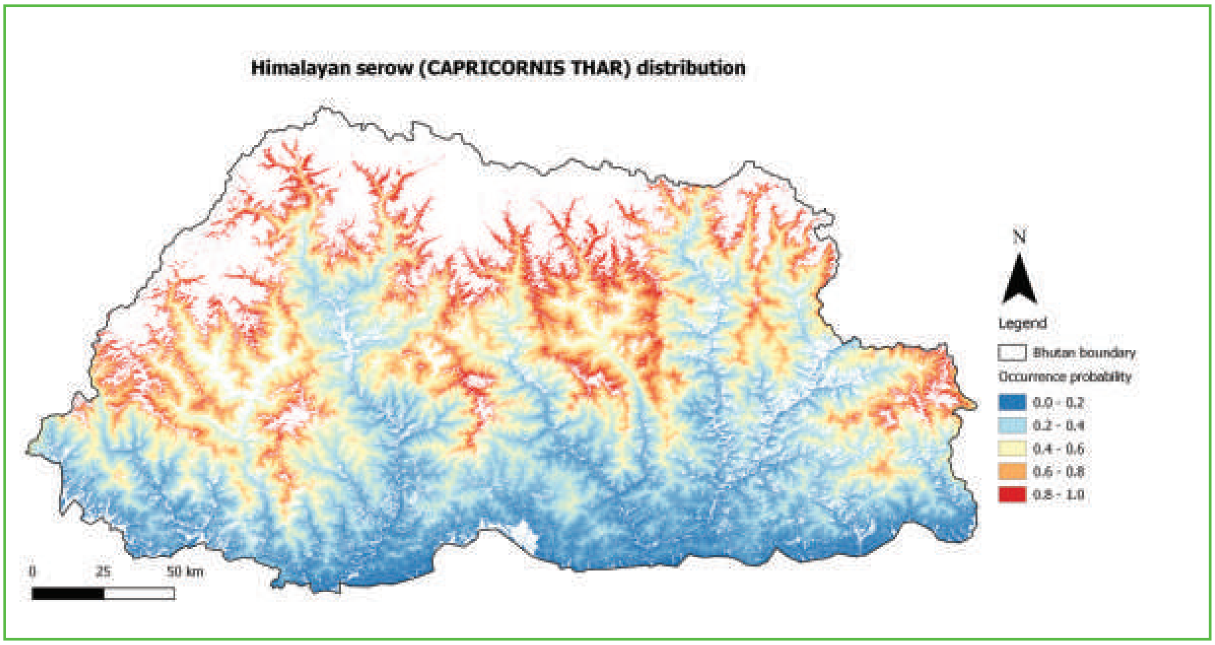


Figure 100: Predicted distribution of Himalayan serow in Bhutan

Serows are expected to be found in high altitude in the temperate region (Figure100s). The habitat overlaps with Himalayan black bears but we don't expect bears to prey on serow because of the large size (except juveniles). Serow is a medium-sized ungulate found mostly solitary. Past records show that serows are found throughout forested habitat from southern foothills up to 3000m (Wangchuk et al., 2004). Current prediction shows mostly in the higher altitudes. The speculation to this discrepancy might be due to false positives (misidentification of pellets of other ungulates as that of serow).

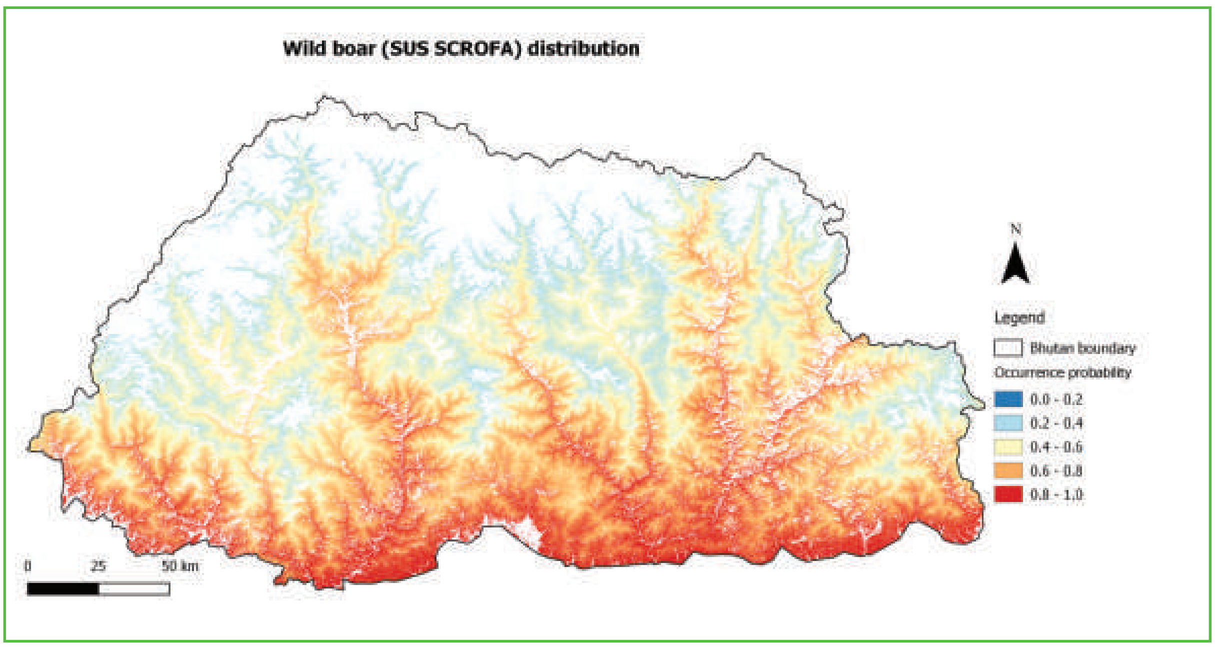


Figure 101: Predicted distribution of wild boar in Bhutan

Of all ungulates, wild boars are most versatile and ubiquitous in distribution. The range extends from subtropical foothills to temperate zone and even up to the tree line (Figure 101). Altitudinal record shows the highest record of wild boars at an elevation of 3500m. Wild boars are the main animal that comes in conflict with farmers in Bhutan. Wild boars raid crops. There is a huge economic loss to farmers due to loss of agriculture yield to wild boars. While they are considered pest, they are also one of the important prey species for large carnivores such as tigers and leopards.

7.3 Discussion

Species distribution and range is shifting, expanding or contracting in the face of global climate change (Chen *et al.*, 2011). To understand the extent and pattern of this change, it is important to model responses in relation to climatic variables. In our analysis, we did not use bioclimatic variables to predict distribution. It is recommend that future studies take this into account and perform robust predictions. Species distribution models are widely used for decision making and preparing conservation action plan of species for management (Guisan *et al.*, 2013). However, with only *apparent* distribution being modelled (from a single visit to the site) only the probable sites of occurrence are presented and show how a species is distributed in Bhutan and the potential areas of occurrence given identical condition as observed site. These maps may not be recommended in totality for conservation management planning.

Caution must be taken while interpreting the prediction maps. This is because NFI data were collected once and does not contain information on the temporal replication. Further, to model true distribution we need to account for detection probability (MacKenzie *et al.*, 2002; MacKenzie *et al.*, 2017). It is not possible to observe all the animals present at a site during one-time observation or visit. Animals may be undetected when present due to observation error or factors related to environment such as weather, temperature, terrain, etc or may be altogether absent. Such stochasticity is common in nature and inherent to animal studies. This is one of the reasons why we need to visit a site more than once (temporal replication). Linear models without accounting for heterogeneity in detection could only model apparent spatial distribution (Kéry and Schaub, 2011). Few observations were too small to model distribution and we are aware that analysis of such data will result in spurious estimates. Most observations were indirect evidence of animals and such data are prone to false positives and false negatives (Petracca *et al.*, 2018). False positive contribute to positive bias while false negative causes negative bias in the estimates.

CHAPTER 08
WAY FORWARD

The estimates presented in report are intended to serve as the baseline information on biomass and carbon, regeneration, annual increment and species diversity and therefore helps to understand the state of our forest resources. It will enable monitoring of changes in forest resources over time and enable improved management of our resources through periodic inventory and assessment.

To begin with, the results and analysis presented in the two volumes of NFI report can be used for preparing policy briefs and directing focused management strategies. For example, the qualitative analysis of forest health and disturbance, provides direction on key disturbance factors that forestry sector must place immediate attention on. This information at national level must direct specific studies and researches to be conducted.

However, for better use of the information and to monitor the forest management and improvement initiatives, this assessment must be followed by periodic inventories for maximum impact and value for informed policy-decisions and management strategies. The monitoring and assessment should be holistic in nature and not restricted to one particular parameter such as timber volume. The next forest inventory will also help in understanding the actual tree growth over the past years and will replace the tree growth data obtained from the increment cores.

For better and effective future NFIs, the report also points out the areas for improvement in scope and scale of data to be collected during the next national forest inventory. Improving the species identification to reduce the number of unknowns would greatly enhance the estimates for biomass and carbon for example and also provide more precise estimates of species diversity. It will also improve the assessment and quantification of NWFPs.

Efforts at collecting more detailed information on pests and diseases and disturbances such as species of mistletoe and number of infected trees would enhance the capacity to inform the state of forest health by being able to quantify potential loss of volume of trees.

The current initiative on NFI in combination with future periodic inventories will provide required information for improving forest and biodiversity management and in monitoring the forest change over time with respect to different disturbances in the face of climate change. Most importantly the periodic inventories are imperative for monitoring 60% forest cover mandate as enshrined in the Constitution of the Kingdom of Bhutan and in reporting and meeting the various international obligations and commitments.

REFERENCE

Ali, S., Begum F., Hayat R., Bohannan B.J. 2017. Variation in soil organic carbon stock in different land uses and altitudes in Bagrot Valley, Northern Karakoram. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science* **67**, 551-561.

Balderas Torres, A., Lovett J.C. 2012. Using basal area to estimate above-ground carbon stocks in forests: La Primavera Biosphere's Reserve, Mexico. *Forestry* **86**, 267-281.

Belay, B., Pötzelsberger E., Sisay K., Assefa D., Hasenauer H. 2018. The Carbon Dynamics of Dry Tropical Afromontane Forest Ecosystems in the Amhara Region of Ethiopia. *Forests* **9**, 18.

Bhat, G., Mughal A., Malik A., Khan P., Shazmeen Q. 2015. Natural Regeneration Status of Blue Pine (Pinus Wallichian) in North West Himalayas, India.

Buffum, B., Gratzer G., Tenzin Y. 2008. The sustainability of selection cutting in a late successional broadleaf community forest in Bhutan. *For Ecol Manage* **256**, 2084-2091.

Burnham, K.P., Anderson D.R. 2004. Multimodel inference: understanding AIC and BIC in model selection. *Sociological methods & research* **33**, 261-304.

Butt, N., Bebber D., Riutta T., Crockatt M., Morecroft M., Malhi Y. 2014. Relationships between tree growth and weather extremes: spatial and interspecific comparisons in a temperate broadleaf forest. *For Ecol Manage* **334**, 209-216.

Chen, I.-C., Hill J.K., Ohlemüller R., Roy D.B., Thomas C.D. 2011. Rapid range shifts of species associated with high levels of climate warming. *Science* **333**, 1024-1026.

Coates, K.D. 2002. Tree recruitment in gaps of various size, clearcuts and undisturbed mixed forest in interior British Columbia, Canada. *For Ecol Manage* **155**, 387-398.

Coomes, D.A., Allen R.B. 2007. Effects of size, competition and altitude on tree growth. *J Ecol* **95**, 1084-1097.

Covey, K., Carroll C.J., Duguid M.C., Dorji K., Dorji T., Tashi S., et al. 2015. Developmental dynamics following selective logging of an evergreen oak forest in the Eastern Himalaya, Bhutan: Structure, composition, and spatial pattern. *For Ecol Manage* **336**, 163-173.

Dar, J.A., Sundarapandian S. 2015. Variation of biomass and carbon pools with forest type in temperate forests of Kashmir Himalaya, India. *Environ Monit Assess* **187**, 55.

Darabant, A. Regeneration status in Chamgang and Gidakom FMUs-Success or failure? Preliminary results of the regeneration inventory. In: Proceedings of the 8th National Forest Research Coordination Workshop, 17–18 February 2005--Rai TB, ed. (2005) National Biodiversity Centre, Serbithang: Renewable Natural Resources Research Centre Yusipang. 33-39.

Darabant, A., Rai P.B., Tenzin K., Roder W., Gratzer G. 2007. Cattle grazing facilitates tree regeneration in a conifer forest with palatable bamboo understory. *For Ecol Manage* **252**, 73-83.

Dean, T.J. 2004. Basal area increment and growth efficiency as functions of canopy dynamics and stem mechanics. *For Sci* **50**, 106-116.

DoFPS. 2011. Forestry Development in Bhutan: Policies, Programmes and Institutions. Department of Forests & Park Services, Ministry of Agriculture & Forests, Royal Government of Bhutan.

Dorji, S., Donaubauer E., Wingfield M.J., Kirisits T. 2012. Himalayan dwarf mistletoe (Arceuthobium minutissimum) and the leafy mistletoe Taxillus kaempferi on blue pine (Pinus wallichiana) in Bhutan. *Journal of Agricultural Extension and Rural Development* **4**, 217-220.

Dorji, T., Odeh I.O., Field D.J., Baillie I.C. 2014. Digital soil mapping of soil organic carbon stocks under different land use and land cover types in montane ecosystems, Eastern Himalayas. *For Ecol Manage* **318**, 91-102.

FAO, 1996. Non-Wood Forest Products of Bhutan (1996/6). The Food and Agriculture Organization of United Nations, Bangkok, Thailand.

FAO. 2018. Forest Health (http://www.fao.org/forestry/pests/en/). Food and Agriculture Organization of the United Nations, Rome. Accessed on 1st July, 2018.

FRMD. 2012. National Forest Inventory Field Manual. Thimphu (Bhutan): Department of Forests & Park Services, Ministry of Agriculture & Forests, Royal Government of Bhutan.

FRMD. 2014. A field Guide for Above-ground Understory and Soil Carbon Assessment. Forest Resources Management Division, Department of Forests & Park Services, Ministry of Agriculture & Forests, Royal Government of Bhutan.

FRMD 2016. *National Forest Inventory Report: Stocktaking Nation's Forest Resources Volume I* Department of Forests & Park Services, Ministry of Agriculture & Forests, Royal Government of Bhutan. Thimphu

FRMD 2017. *ATLAS OF BHUTAN: LANDUSE LANDCOVER 2016 STATISTICS* Forest Resources Management Divsion, Department of Forests & Park Services, Ministry of Agriculture & Forests, Royal Government of Bhutan. Thimphu, Bhutan

FSI. 2017. India State of Forest Report. Forest Survey of India, Ministry of Environment Forest and Climate Change, Kaulagarh Road, P.O-IPE Dehradun-248195, Uttarakhand, India.

Führer, E. 2000. Forest functions, ecosystem stability and management. *For Ecol Manage* **132**, 29-38.

Gairola, S., Sharma C., Ghildiyal S., Suyal S. 2011a. Live tree biomass and carbon variation along an altitudinal gradient in moist temperate valley slopes of the Garhwal Himalaya (India). *Curr Sci*, 1862-1870.

Gairola, S., Sharma C.M., Suyal S., Ghildiyal S.K. 2011b. Composition and diversity of five major forest types in moist temperate climate of the western Himalayas. *Forestry Studies in China* **13**, 139.

Guisan, A., Edwards Jr T.C., Hastie T. 2002. Generalized linear and generalized additive models in studies of species distributions: setting the scene. *Ecol Model* **157**, 89-100.

Guisan, A., Tingley R., Baumgartner J.B., Naujokaitis-Lewis I., Sutcliffe P.R., Tulloch A.I., et al. 2013. Predicting species distributions for conservation decisions. *Ecol Lett* **16**, 1424-1435.

Hansen, M.C., Potapov P.V., Moore R., Hancher M., Turubanova S., Tyukavina A., et al. 2013. High-resolution global maps of 21st-century forest cover change. *science* **342**, 850-853.

Hasenauer, H. 2006. *Sustainable Forest Management: Growth Models for Europe.* Springer. Berlin, Germany, 398 pp.
Hein, S., Dhôte J.-F. 2006. Effect of species composition, stand density and site index on the basal area increment of oak trees (Quercus sp.) in mixed stands with beech (Fagus sylvatica L.) in northern France. *Ann Forest Sci* **63**, 457-467.
Husch, B., Beers T.W., Kershaw Jr J.A. 2002. *Forest mensuration.* John Wiley & Sons. New York, USA.
IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.
Joshi, H., Samant S. 2004. Assessment of forest vegetation and conservation priorities of communities in part of Nanda Devi Biosphere Reserve, West Himalaya. Part I. *The International Journal of Sustainable Development & World Ecology* **11**, 326-336.
Karanth, K.U. 2001. *The way of the tiger: natural history and conservation of the endangered big cat* Voyageur Press.
Karki, S., Joshi N., Udas E., Adhikari M., Sherpa S., Kotru R., et al. 2016. Assessment of forest carbon stock and carbon sequestration rates at the ICIMOD Knowledge Park at Godavari. *ICIMOD Working Paper*.
Kaźmierczak, K. 2013. The current growth increment of pine tree stands comprising three different age classes. *Forest Research Papers* **74**, 93-100.
Keith, H., Mackey B.G., Lindenmayer D.B. 2009. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. *Proceedings of the National Academy of Sciences*, pnas. 0901970106.
Kéry, M., Schaub M. 2011. *Bayesian population analysis using WinBUGS: a hierarchical perspective* Academic Press.
Khun, V., Sasaki N. 2014. Re-Assessment of Forest Carbon Balance in Southeast Asia: Policy Implications for REDD+. *Low Carbon Economy* **5**, 153.
King, G.M., Gugerli F., Fonti P., Frank D.C. 2013. Tree growth response along an elevational gradient: climate or genetics? *Oecologia* **173**, 1587-1600.
Lin, D., Lai J., Muller-Landau H.C., Mi X., Ma K. 2012. Topographic variation in above-ground biomass in a subtropical evergreen broad-leaved forest in China. *PloS one* **7**, e48244.
Lomolino, M. 2001. Elevation gradients of species-density: historical and prospective views. *Global Ecol Biogeogr* **10**, 3-13.
Lutz, J.A., Larson A.J., Freund J.A., Swanson M.E., Bible K.J. 2013. The importance of large-diameter trees to forest structural heterogeneity. *PLoS One* **8**, e82784.
MacKenzie, D.I., Nichols J.D., Lachman G.B., Droege S., Andrew Royle J., Langtimm C.A. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* **83**, 2248-2255.
MacKenzie, D.I., Nichols J.D., Royle J.A., Pollock K.H., Bailey L., Hines J.E. 2017. *Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence* Elsevier.
McKinney, M.L. 2002. Urbanization, Biodiversity, and Conservation The impacts of urbanization on native species are poorly studied, but educating a highly urbanized human population about these impacts can greatly improve species conservation in all

ecosystems. *Bioscience* **52**, 883-890.
Mendoza-Ponce, A., Galicia L. 2010. Above-ground and below-ground biomass and carbon pools in highland temperate forest landscape in Central Mexico. *Forestry* **83**, 497-506.
Mokany, K., Raison R.J., Prokushkin A.S. 2006. Critical analysis of root: shoot ratios in terrestrial biomes. *Global Change Biol* **12**, 84-96.
Moktan, M.R., Gratzer G., Richards W.H., Rai T.B., Dukpa D., Tenzin K. 2009. Regeneration of mixed conifer forests under group tree selection harvest management in western Bhutan Himalayas. *For Ecol Manage* **257**, 2121-2132.
Moktan, M.R., Norbu L., Dukpa K., Rai T.B., Dendup K., Gyeltshen N. 2007. Bamboo and Cane: Potential for Poverty Reduction and Forest Conservation. *Journal of Renewable Natural Resources, Bhutan* **3**, 38-67.
Moktan, M.R., Norbu L., Nirola H., Dukpa K., Rai T.B., Dorji R. 2008. Ecological and social aspects of transhumant herding in Bhutan. *Mt Res Dev* **28**, 41-48.
Monserud, R.A., Sterba H. 1996. A basal area increment model for individual trees growing in even-and uneven-aged forest stands in Austria. *For Ecol Manage* **80**, 57-80.
Norbu, L. 2002. Grazing management in Broadleaf Forests. *Journal of Bhutan Studies* **7**, 99-129.
NSSC. 2017. Digital Soil Mapping of Soil Organic Carbon Stock in Bhutan. National Soil Services Centre, Department of Agriculture, Ministry of Agriculture & Forests, Royal Government of Bhutan.
Ohsawa, M. 1987. *Life zone ecology of the Bhutan Himalaya I* Chiba University. Chiba, Japan.
Ohsawa, M. 1991. *Life Zone Ecology of Bhutan Himalaya II* Chiba University. Chiba, Japan
Ohsawa, M. 2002. *Life Zone Ecology of Bhutan Himalaya III* Chiba University. Chiba, Japan
Oksanen, R. 2017. Vegan: ecological diversity:processed with vegan 2.4-4 in R Under development (unstable) (2017-08-24 r73119) on August 24, 2017.
Panwar, V.P., Gupta M. 2013. Soil organic carbon pool under different forest types in Himachal Pradesh. *International Journal of Farm Sciences* **3**, 81-89.
Petracca, L.S., Frair J.L., Cohen J.B., Calderón A.P., Carazo-Salazar J., Castañeda F., et al. 2018. Robust inference on large-scale species habitat use with interview data: The status of jaguars outside protected areas in Central America. *J Appl Ecol* **55**, 723-734.
Petrokofsky, G., Kanamaru H., Achard F., Goetz S.J., Joosten H., Holmgren P., et al. 2012. Comparison of methods for measuring and assessing carbon stocks and carbon stock changes in terrestrial carbon pools. How do the accuracy and precision of current methods compare? A systematic review protocol. *Environmental Evidence* **1**, 6.
Pielou, E.C. 1969. *An introduction to mathematical ecology* Wiley-Interscience. New York
Pokharel, B., Dech J.P. 2012. Mixed-effects basal area increment models for tree species in the boreal forest of Ontario, Canada using an ecological land classification approach to incorporate site effects. *Forestry* **85**, 255-270.
Pour, M.J., Mohadjer, M.R.M., Etemad, V. et al. 2012. Effects of grazing on natural regeneration of tree and herb species of Kheyroud forest in northern Iran. Journal of Forestry Research 23: 299. https://doi.org/10.1007/s11676-012-0256-2
Pradhan, B., Awasthi K., Bajracharya R. 2012. Soil organic carbon stocks under different forest types in Pokhare khola sub-watershed: a case study from Dhading district of Nepal. *WIT*

Transactions on Ecology and the Environment **157**, 535-546.
Rasel, S. M. M. (2013). Effect of elevation and above ground biomass (AGB) on soil organic carbon (SOC): a remote sensing based approach in Chitwan district, Nepal. *International Journal Scientific & Engineering Research*, 1546-1553.
Rawat, B., Gairola S., Sekar K.C., Rawal R. 2014. Community structure, regeneration potential and future dynamics of natural forest site in part of Nanda Devi Biosphere Reserve, Uttarakhand, India. *African Journal of Plant Science* **8**, 380-391.
Rosset, J. 1999. *Temperate conifer forests of Bhutan: A review of forestry research activities until June,1998* Research Extension and Irrigation Division, Ministry of Agriculture, Royal Government of Bhutan. Bumthang, Bhutan.
Salunkhe, O., Khare P., Kumari R., Khan M. 2018. A systematic review on the above-ground biomass and carbon stocks of Indian forest ecosystems. *Ecological Processes* **7**, 17.
Sardans, J., Peñuelas J. 2013. Tree growth changes with climate and forest type are associated with relative allocation of nutrients, especially phosphorus, to leaves and wood. *Global Ecol Biogeogr* **22**, 494-507.
Scharlemann, J.P., Tanner E.V., Hiederer R., Kapos V. 2014. Global soil carbon: understanding and managing the largest terrestrial carbon pool. *Carbon Management* **5**, 81-91.
SFED, 2011. Interim framework for management and marketing of Non-Wood forest products.
Shannon, C.E., Weaver W. 1949. *The mathematical theory of communication* University of Illinois Press, Urbana,117pp.
Sharma, C.M., Baduni N.P., Gairola S., Ghildiyal S.K., Suyal S. 2010. Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India. *For Ecol Manage* **260**, 2170-2179.
Simon, A., Dhendup K., Rai P., Gratzer G. 2018. Soil carbon stocks along elevational gradients in Eastern Himalayan mountain forests. *Geoderma regional* **12**, 28-38.
Singh, J., Singh S. 1987. Forest vegetation of the Himalaya. *Bot Rev* **53**, 80-192.
Sisay, K., Thurnher C., Belay B., Lindner G., Hasenauer H. 2017. Volume and carbon estimates for the forest area of the amhara region in northwestern ethiopia. *Forests* **8**, 122.
Smith, C.D., Pontius J.S. 2006. Jackknife estimator of species richness with S-PLUS.
Smith, R., Nichols J. 2005. Patterns of basal area increment, mortality and recruitment were related to logging intensity in subtropical rainforest in Australia over 35 years. *For Ecol Manage* **218**, 319-328.
Stapleton, C., Barrow S., Pradhan R. 1997. Bamboo and cane study of Zhemgang Dzongkhag. *Ministry of Agriculture, Thimphu.*
Stergiadi, M., Van Der Perk M., De Nijs T., Bierkens M.F. 2016. Effects of climate change and land management on soil organic carbon dynamics and carbon leaching in northwestern Europe. *Biogeosciences* **13**, 1519-1536.
Tenzin, J., Hasenauer H. 2016. Tree species composition and diversity in relation to anthropogenic disturbances in broad-leaved forests of Bhutan. *Int J Biodivers Sci Ecosyst Serv Manage* **12**, 274-290.
Tenzin, J., Tenzin K., Hasenauer H. 2017a. Individual tree basal area increment models for broadleaf forests in Bhutan. *Forestry: An International Journal of Forest Research* **90**, 367-

380.
Tenzin, J., Wangchuk T., Hasenauer H. 2017b. Form factor functions for nine commercial tree species in Bhutan. *Forestry: An International Journal of Forest Research* **90**, 359-366.
Tenzin, K. 2008. Regeneration and gap dynamics in mixed conifer forests in the Bhutan Himalayas. Vienna, Austria: BOKU University.
Thinley, P., Lham D., Wangchuk S., Wangchuk N. 2016. National Snow Leopard Survey of Bhutan 2014-2016 (Phase I): Sign and Prey Base Survey. Department of Forests & Park Services, Ministry of Agriculture & Forests, Royal Government of Bhutan.
UN-REDD. 2018. About REDD+(https://unredd.net/about/what-is-redd-plus.html). Accessed on 20th May, 2018.
USGS. 2016. Shuttle Radar Topography Mission. United States Geological Survey. https://lta.cr.usgs.gov/SRTM. Accessed June, 2016.
UWICER 2017. *Dendrochronology Manual* Ugyen Wangchuck Institute for Conservation and Environmental Research. Lamai Goempa, Bumthang, Bhutan
Walkley, A., Black I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science* **37**, 29-38.
Wangchuk et al., 2016. Medicinal plants of Dagala region in Bhutan: their diversity, distribution, uses and economic potential. *Journal of Ethnobiology and Ethnomedicine, 12:28.*
Wangda, P., Ohsawa M. Transition of forest structure and environmental conditions along the altitudinal gradient in a dry valley, upper Lobesa, Bhutan. In: IUCN/WCPA-EA-4 Taipei Conference (2002) Taipei, Taiwan. 8.
Wangda, P., Ohsawa M. 2006a. Structure and regeneration dynamics of dominant tree species along altitudinal gradient in a dry valley slopes of the Bhutan Himalaya. *For Ecol Manage* **230**, 136-150.
Wangda, P., Ohsawa M. 2006b. Gradational forest change along the climatically dry valley slopes of Bhutan in the midst of humid eastern Himalaya. *Plant Ecol* **186**, 109-128.
Watkins, R.Z., Chen J., Pickens J., Brosofske K.D. 2003. Effects of forest roads on understory plants in a managed hardwood landscape. *Conserv Biol* **17**, 411-419.
West, P. 1980. Use of diameter increment and basal area increment in tree growth studies. *Can J For Res* **10**, 71-77.
Worbes, M. 1995. How to measure growth dynamics in tropical trees a review. *IAWA journal* **16**, 337-351.
Yigini, Y., Panagos P. 2016. Assessment of soil organic carbon stocks under future climate and land cover changes in Europe. *Sci Total Environ* **557**, 838-850.
Zhu, B., Wang X., Fang J., Piao S., Shen H., Zhao S., et al. 2010. Altitudinal changes in carbon storage of temperate forests on Mt Changbai, Northeast China. *J Plant Res* **123**, 439-452.

APPENDIX 1:
ESTIMATES OF BIOMASS AND CARBON

Table 12: Total biomass estimates (in million tonnes) by carbon pool constituents for forest and non-forest with ± margin of error at 90% confidence level

Category	ABG Trees	BGB Trees	ABG Sapling	BGB Sapling	Shrubs	Herbs	Litter	CWD
Forest	657± 40	291 ± 16	72 ± 28	25 ± 7	4.72 ± 0.78	2.07 ± 0.44	39 ± 6	18.14 ± 7.51
Non-Forest	41 ± 6	19 ± 3	14 ± 6	5 ± 2	1.34 ± 0.57	0.42 ± 0.14	8 ± 5	1.16 ± 0.92

Table 13: Biomass density estimates (tonnes per hectare) by carbon pool constituents for forest and non-forest with ± margin of error at 90% confidence level

Category	ABG Trees	BGB Trees	ABG Sapling	BGB Sapling	Shrubs	Herbs	Litter	CWD
Forest	241 ±14	112 ±5	26 ±10	9 ±3	1.61 ±0.27	0.71 ±0.15	13.25 ±2	6.44 ±3
Non-Forest	37 ±6	19 ±2	12 ±6	5 ±2	1.49 ±0.57	0.46 ±0.12	8.96 ±6	1.14 ±1

Table 14: Total biomass estimates (in million tonnes) by Dzongkhag with ± margin of error at 90% confidence level

District	AGB Tree	AGB Sapling	BGB Tree	BGB Sapling	Shrub	Herb	CWD	Litter
Bumthang	47 ±14	3.2± 2.48	21 ± 6	1.33 ± 0.85	0.2 ± 0.13	0.236 ± 0.287	3.18 ± 2.45	3.6 ± 1.92
Chhukha	56 ± 19	3.16 ± 4.09	24 ± 7	1.23 ± 1.38	0.19 ± 0.13	0.131 ± 0.114	3.14 ± 3.34	3.48 ± 2.58
Dagana	32 ± 7	1.03 ± 0.46	15 ± 3	0.56 ± 0.21	0.24 ± 0.18	0.072 ± 0.067	0.08 ± 0.13	1.2 ± 0.7
Gasa	5 ± 2	0.19 ± 0.11	2 ± 1	0.11 ± 0.06	0 ± 0.01	0.008 ± 0.017	0 ± 0.01	0 ± 0
Haa	35 ± 9	2.31 ± 1.58	16 ± 4	1 ± 0.57	0.1 ± 0.15	0.007 ± 0.006	1.09 ± 0.64	1.12 ± 1.09
Lhuntse	50 ± 17	1.39 ± 1.55	21 ± 7	0.63 ± 0.59	0.37 ± 0.41	0.212 ± 0.191	2.02 ± 3.17	1.85 ± 0.9
Mongar	60 ± 16	1.19 ± 0.54	26 ± 7	0.63 ± 0.26	0.45 ± 0.39	0.264 ± 0.188	1.26 ± 0.93	5.18 ± 4.5
Paro	16 ± 5	4.18 ± 5.55	7 ± 2	1.38 ± 1.71	0.11 ± 0.14	0.003 ± 0.004	0.81 ± 1.49	0.7 ± 0.78
Pemagatshel	11 ± 3	0.64 ± 0.63	5 ± 2	0.3 ± 0.23	0.12 ± 0.11	0.042 ± 0.046	0.06 ± 0.07	0.63 ± 0.43
Punakha	30 ± 14	6.56 ± 11.76	13 ± 6	1.86 ± 3	0.18 ± 0.19	0.048 ± 0.053	1.81 ± 1.52	0.67 ± 0.66
Samdrup Jongkhar	46 ± 13	0.76 ± 0.42	20 ± 5	0.45 ± 0.17	0.28 ± 0.2	0.118 ± 0.081	0.49 ± 0.42	3.77 ± 2.1
Samtse	13 ± 4	0.24 ± 0.09	6 ± 2	0.15 ± 0.05	0.37 ± 0.27	0.069 ± 0.091	0.14 ± 0.19	0.35 ± 0.2
Sarpang	24 ± 6	0.34 ± 0.1	11 ± 2	0.23 ± 0.07	0.39 ± 0.41	0.097 ± 0.048	0.24 ± 0.2	1.13 ± 0.59
Thimphu	18 ± 5	15.29 ± 23.54	8 ± 3	4.57 ± 6.43	0.07 ± 0.09	0.047 ± 0.063	0.31 ± 0.3	1.96 ± 1.68
Trashigang	57 ± 13	5.35 ± 4.77	26 ± 5	2.01 ± 1.46	0.38 ± 0.23	0.065 ± 0.044	2.59 ± 3.94	2.85 ± 3.59
Trashiyangtse	19 ± 6	10.07 ± 18.27	8 ± 3	2.66 ± 4.46	0.18 ± 0.17	0.045 ± 0.034	0.4 ± 0.45	1.1 ± 0.74
Trongsa	34 ± 10	1.12 ± 0.46	15 ± 4	0.57 ± 0.2	0.22 ± 0.19	0.15 ± 0.208	0.25 ± 0.28	1.09 ± 0.71
Tsirang	21 ± 10	0.27 ± 0.24	9 ± 4	0.16 ± 0.12	0.04 ± 0.06	0.035 ± 0.072	-2.46 ± 3.02	0.68 ± 0.75
Wangdue Phodrang	52 ± 13	8.92 ± 8.18	23 ± 5	3.02 ± 2.38	0.25 ± 0.2	0.021 ± 0.023	1.3 ± 0.97	2.83 ± 2.17
Zhemgang	32 ± 6	2.96 ± 2.3	15 ± 3	1.26 ± 0.82	0.36 ± 0.2	0.312 ± 0.23	0.44 ± 0.55	3.71 ± 1.64

Table 15: Biomass density estimates (tonnes per hectare) by Dzongkhag with ± margin of error at 90% confidence level

Dzongkhag	AGB Trees	BGB Trees	AGB Sapling	BGB Sapling	Shrubs	Herbs	Litter	CWD
Bumthang	298 ±66	131 ±24	21 ±16	9 ±5	1.12 ±0.5	1.32±1.45	20.01 ±5.83	19.03 ±33.24
Chhukha	325 ±92	138 ±35	18 ±24	7±8	1.04 ±0.54	0.73 ±0.51	19.23 ±10.87	19.82 ±42.84
Dagana	185 ±25	84 ±10	6 ±2	3 ±1	1.52 ±0.97	0.45 ±0.34	7.57 ±2.46	0.54 ±1.22
Gasa	128 ±30	61 ±13	5 ±2	3 ±1	0.29 ±0	0.72 ±0	0 ±0	0.11±0.36
Haa	270 ±43	119 ±17	18 ±12	8 ±4	1.04 ±1.35	0.07 ±0.05	12.48 ±8.33	9.81 ±14.83
Lhuntse	458 ±108	190 ±42	13 ±13	6 ±5	1.73 ±1.52	0.98 ±0.79	8.51 ±1.97	4.1±10.45
Mongar	348 ±68	150 ±27	7 ±3	4 ±1	2.53 ±1.76	1.46 ±0.77	28.58 ±20.18	7.71 ±12.95
Paro	176 ±34	82 ±14	47 ±63	16 ±19	2.49 ±1.5	0.07 ±0.06	15.78 ±17.23	14.09 ±41.34
Pemagatshel	102 ±16	51 ±7	6±6	3 ±2	1.27 ±0.77	0.4 ±0.37	6.2 ±1.6	0.44±1.02
Punakha	361 ±144	154 ±55	77 ±145	22 ±37	2.04 ±1.76	0.54 ±0.53	7.51 ±4.69	24 ±43.37
Samdrup Jongkhar	283 ±62	122 ±24	5 ±2	3 ±1	1.24 ±0.81	0.51 ±0.27	16.19 ±6.67	3.7 ±6.58
Samtse	132 ±22	61 ±9	2±1	1 ±0	3.25 ±1.43	0.62 ±0.76	3.05 ±0.62	1.2 ±3.07
Sarpang	150 ±20	69 ±9	2±0	1 ±0	1.95 ±1.6	0.47 ±0.15	5.52 ±1.55	1.42±2.61
Thimphu	176 ±34	83±15	154±230	46 ±62	0.93 ±0.9	0.64 ±0.58	24.33 ±13.51	3.74±6.98
Trashigang	258±40	115 ±16	25±22	9 ±6	1.61 ±0.71	0.27 ±0.15	11.8 ±12.65	11.09 ±27.35
Trashiyangtse	208±39	93 ±15	110 ±201	29 ±50	1.6 ±1.15	0.39 ±0.17	9.59 ±2.88	3.88±7.45
Trongsa	250 ±48	111 ±19	8 ±3	4 ±1	1.41 ±0.9	0.91 ±1.12	6.87 ±2.69	1.48±3.31
Tsirang	300±126	132±51	4 ±3	2 ±1	0.97 ±0.82	0.76 ±1.33	15.64 ±8.01	33.42 ±90.76
Wangdue phodrang	215±44	96±17	37±33	12 ±10	1.36 ±0.97	0.11 ±0.12	15.44 ±9.74	5.15±8.98
Zhemgang	146±17	68 ±7	14±10	6 ±3	1.39 ±0.53	1.17 ±0.8	13.98 ±3.32	3.31 ±5.93

Table 16 : Above-ground biomass estimates of total and density by DBH class with ± margin of error at 90% confidence level

DBH Class	Total above-ground biomass(in million tonnes)	Above ground biomass density(t/ha)
10-20 cm	20.57±1.1	7.54±0.32
20-30 cm	37.58±1.67	13.77±0.46
30-40 cm	44.09±1.87	16.17±0.61
40-50 cm	48.36±2.57	17.75±0.81
50-60 cm	53.71±2.87	19.69±0.93
60-70 cm	58.88±3.69	21.49±1.22
70-80 cm	55.79±3.93	20.43±1.35
80-90 cm	58.09±5.34	21.32±1.88
90-100 cm	48.25±4.78	17.78±1.7
100-110 cm	31.99±4.15	11.78±1.46
110-120 cm	34.25±4.75	12.62±1.68
120-130 cm	30.7±5.2	11.28±1.8
130-140 cm	27.64±5.35	10.2±1.92
140-150 cm	21.49±5.61	7.96±1.76
150-160 cm	19.97±5.51	7.36±1.94
160-170 cm	17.12±4.92	6.34±1.62
170-180 cm	12.52±3.88	4.52±1.65
180-190 cm	21.95±6.36	8±2.32
>=190 cm	12.18±4.09	4.47±1.43

Table 17: Above-ground biomass estimates of both total and density by species with ± margin of error at 90% confidence level

Species	Total AGB(in million tonnes)	AGB density(t/ha)
Abies densa	85.43±15.27	215.52±32.47
Acer sp.	23.81±5.78	53.88±11.29
Ailanthus integrifolia	0.5±0.28	20.46±7.94
Alnus sp.	8.85±4.3	72.53±32.8
Aphanamixis polystachya	0.56±0.35	17.31±7.66
Beilschmiedia sp.	3.51±0.87	23.29±4.1
Betula sp.	14.38±3.07	45.89±9.12
Bombax ceiba	0.75±0.48	34±20.05
Castanopsis sp.	28.56±5.31	68.84±9.82
Cupressus sp.	0.01±0.03	6.23±2.45
Duabanga grandiflora	3.61±2.64	78.25±43.38
Engelhardtia spicata	4.55±1.87	32.87±12.48
Juniperus sp.	5.89±2.58	65.86±24.12
Larix griffithii	0.44±0.36	32.54±12.21
Magnolia sp.	14.91±2.74	54.62±8.21
Persea sp.	32.63±7.79	89.06±18.1
Phoebe hainesiana	0.36±0.72	237.92±0
Picea spinulosa	9.09±4.74	91.13±40.65
Pinus roxburghii	21.58±13.66	201.36±109.35
Pinus wallichiana	27.46±18.77	159.84±96.7
Quercus sp.	111.7±12.79	128.86±12.1
Rhododendron sp.	30.7±6	42.2±7.26
Schima wallichii	10.69±4.63	48.02±19.3
Sterculia vilosa	0.67±0.49	25.43±17.02
Symplocos cochinchinensis	0.08±0.07	8.65±2.82
Terminalia myriocarpa	0.28±0.39	57.38±53.88
Tetrameles nudiflora	2.24±1.23	85.38±38.89
Tsuga dumosa	23.69±7.86	165.03±40.25
Others	184.7±14.32	72.58±5.14

Table 18: Total Biomass estimates (in million tonnes) by forest type with ± margin of error at 90% confidence level

Forest Type	ABG trees	BGB tree	Agb Sapling	BGB Saping	Shrub	Herb	Litter	CWD
Subtropical forest	26.41 ± 4.57	12.57 ± 2.16	0.823 ± 0.18	0.537 ± 0.105	0.47 ± 0.227	0.162 ± 0.141	1.7 ± 0.825	0.453 ± 0.306
Warm Broad-leaved Forests	116.98 ± 14.74	53.34 ± 6.38	4.532 ± 2.418	2.182 ± 0.817	1.44 ± 0.53	0.618 ± 0.246	9.165 ± 2.696	1.681 ± 0.881
Chirpine Forest	23.3 ± 15.23	9.82 ± 5.99	2.059 ± 3.076	0.724 ± 0.917	0.208 ± 0.2	0.133 ± 0.165	1.135 ± 0.709	0.14 ± 0.197
Cool Broad-leaved Forest	307.37 ± 30.98	133.59 ± 12.89	24.725 ± 21.856	8.545 ± 5.318	1.729 ± 0.629	0.717 ± 0.259	13.747 ± 4.736	9.318 ± 4.992
Evergreen Oak Forest	8 ± 4.17	3.67 ± 1.86	3.523 ± 3.816	1.148 ± 1.172	0.003 ± 0.005	0.002 ± 0.005	0.262 ± 0.524	0.416 ± 0.78
Blue Pine Forest	27.9 ± 18.43	12.43 ± 7.02	26.067 ± 23.97	8.086 ± 6.43	0.114 ± 0.101	0.043 ± 0.045	1.794 ± 1.163	1.095 ± 1.697
Spruce Forest	11.81 ± 6.99	5.1 ± 2.79	0.818 ± 0.866	0.36 ± 0.331	0.085 ± 0.091	0.004 ± 0.004	1.386 ± 1.286	0.281 ± 0.31
Hemlock Forest	30.15 ± 9.32	12.96 ± 3.83	0.739 ± 0.532	0.368 ± 0.232	0.11 ± 0.108	0.114 ± 0.169	2.825 ± 3.692	0.732 ± 0.947
Fir Forest	93.24 ± 15.68	41.84 ± 6.75	5.595 ± 4.309	2.247 ± 1.351	0.398 ± 0.227	0.167 ± 0.241	5.963 ± 3.124	3.342 ± 5.116
Juniper Rhododendron Scrub	7.77 ± 3.51	3.81 ± 1.65	0.293 ± 0.154	0.165 ± 0.08	0.034 ± 0.051	0.047 ± 0.077	0.2 ± 0.382	0.238 ± 0.223
Dry Alpine Scrub	0.07 ± 0.12	0.04 ± 0.06	0.003 ± 0.007	0.002 ± 0.004				

Table 19: Biomass density (tonnes per hectare) density by forest type with ± margin of error at 90% confidence level

Forest types	Abg Trees	BGB Trees	ABG Sapling	BGB Sapling	Shrubs	Herbs	Litter	CWD
Subtropical Forest	109 ±13	52 ±5	3 ±0	2 ±0	1.77 ±0.7	0.62 ±0.47	6.48 ±2.03	1.72 ±1.14
Warm Broad-leaved Forest	169 ±15	77 ±6	7 ±3	3 ±1	1.75 ±0.5	0.74 ±0.27	11.01 ±2.61	2.33 ±1.24
Chirpine Forest	238 ±130	101 ±49	21 ±30	7 ±9	1.74 ±0.6	1.09 ±1.15	8.91 ±3.28	1.38 ±2.02
Cool Broad-leaved Forest	312 ±26	136 ±10	25 ±22	9 ±5	1.24 ±0.8	0.71 ±0.25	13.74 ±4.12	9.24 ±4.89
Evergreen Oak Forest	255 ±73	117 ±30	110 ±132	36 ±41	0.23 ±0	0.2 ±0	22.65 ±0	12.05 ±23.65
Blue Pine Forest	203 ±119	90 ±44	190 ±172	59 ±48	0.84 ±1.3	0.47 ±0.46	19.57 ±3.97	9.89 ±14.18
Spruce Forest	292 ±154	126 ±58	20 ±19	9 ±7	1.28 ±0.8	0.06 ±0.04	21.79 ±8.85	5.92 ±5.75
Hemlock Forest	344 ±65	148 ±25	9 ±5	4 ±2	0.97 ±0.8	0.99 ±1.3	24.83 ±28.83	9.12 ±11.37
Fir Forest	266 ±29	119 ±12	16 ±12	6 ±4	1.28 ±0.6	0.55 ±0.75	19.14 ±7.27	9.72 ±14.21
Juniper-Rhododendron Scrub	136 ±36	67 ±17	5 ±2	3 ±1	0.63 ±0.7	0.82 ±1.21	3.34 ±6.65	3.7 ±3.34
Dry Alpine Scrub	28 ±48	16 ±25	1 ±2	1 ±1	1.65 ±1.3	-	-	-

Table 20: Total biomass estimates (in million tonnes) for Broadleaf and Conifer forest with ± margin of error at 90% confidence level

Forest category	AGB tree	BGB tree	AGB Sapling	BGB Sapling	Shrub	Herb	Litter	CWD
Broadleaf forest	449 ± 34	199 ± 14	25.7 ± 19.64	10.04 ± 4.93	3.66 ± 0.75	1.5 ± 0.38	24.97 ± 5.44	11.72 ± 5.19
Coniferous forest	203 ± 32	89 ± 13	42.32 ± 26.74	13.77 ± 7.28	0.86 ± 0.27	0.54 ± 0.3	13.36 ± 4.68	6.16 ± 5.31

Table 21: Biomass density estimates (tonnes per hectare) for Broadleaf and Conifer forest with ± margin of error at 90% confidence level

Forest category	ABG Trees	BGB Trees	ABG Sapling	BGB Sapling	Shrubs	Herbs	Litter	CWD
Broadleaf forest.	236 ±16	105 ±6	14 ±10	5 ±3	1.77 ±0.34	0.72 ±0.16	11.99 ±2.42	5.94 ±2.62
Conifer forest.	267 ±34	118 ±13	56 ±33	18 ±9	1.12 ±0.35	0.72 ±0.38	17.35 ±5.03	7.98 ±7.03

Table 22: Total Biomass estimates (in million tonnes) by Elevation range with ± margin of error at 90% confidence level

Elevation range	AGB tree	BGB trees	AGB Sapling	BGB Sapling	Shrub	Herb	Litter	CWD
Less than 1000 m	45 ± 7	20.92 ± 3.18	2.02 ± 1.55	1 ± 0.51	0.72 ± 0.28	0.2 ± 0.11	3.24 ± 1.1	0.41 ± 0.28
1000-2000 m	161 ± 22	72.32 ± 8.97	16 ± 10.56	5.74 ± 2.81	1.82 ± 0.54	0.78 ± 0.3	11.2 ± 3.71	3.27 ± 1.38
2000-3000 m	289 ± 33	125.73 ± 13.48	44.4 ± 25.7	14.38 ± 6.85	1.45 ± 0.56	0.64 ± 0.26	14.07 ± 5.68	7.6 ± 5.04
3000-4000 m	160 ± 22	70.65 ± 9.26	9.8 ± 3.86	4.02 ± 1.26	0.7 ± 0.27	0.4 ± 0.3	9.95 ± 3.5	6.61 ± 5.44
>=4000 m	2 ± 1	0.85 ± 0.58	0.08 ± 0.05	0.04 ± 0.03				

Table 23: Biomass density estimates (tonnes per hectare) by elevation range with ± margin of error at 90% confidence level

Elevation range	AGB Trees	BGB Trees	AGB Sapling	BGB Sapling	Shrubs	Herbs	Litter	CWD
Less than 1000 m	117 ±13	55 ±5	5 ±4	3 ±1	2 ±0.5	0.45 ±0.21	7.26 ±1.51	0.98 ±0.67
1000-2000 m	196 ±22	88 ±9	20 ±13	7 ±3	2 ±0.5	0.8 ±0.26	11.34 ±3.15	3.75 ±1.55
2000-3000 m	313 ±29	136 ±11	48 ±28	16 ±7	2 ±0.6	0.74 ±0.26	16.42 ±5.47	8.24 ±5.37
3000-4000 m	276 ±29	122 ±11	17 ±7	7 ±2	1 ±0.4	0.65 ±0.43	16 ±4.33	11.31 ±9.36
4000 m and above	93 ±42	45 ±17	4 ±2	2 ±1				0 ±0

APPENDIX 2:
SOIL ORGANIC CARBON ESTIMATES

Table 24: Total Soil Organic Carbon estimates (in million tonnes) for forest and non-forest with ± margin of error at 90% confidence level

Category	0-30 cm	0-10cm	10-20 cm	20-30cm
Forest	187.85 ± 16.12	76.55 ± 7.23	59.81 ± 5.37	50.89 ± 5.25
Non Forest	52.43 ± 9.99	20.68 ± 4.05	16.95 ± 3.89	14.46 ± 3.51

Table 25: Soil Organic Carbon density estimates (tonnes per hectare) for forest and non-forest with ± margin of error at 90% confidence level

Category	0-30 cm	0-10cm	10-20 cm	20-30cm
Forest	64.068 ± 4.17	26.208 ± 2.132	20.431 ± 1.445	26.208 ± 2.132
Non Forest	57.956 ± 6.83	22.664 ± 2.737	18.719 ± 2.566	22.664 ± 2.737

Table 26: Total Soil Organic Carbon estimates (in million tonnes) by Dzongkhag with ± margin of error at 90% confidence level

Dzongkhag	0-30 cm	0-10cm	10-20cm	20-30cm
Bumthang	14.25 ± 6.12	5.36 ± 2.46	5.04 ± 2.4	3.64 ± 1.78
Chhukha	10.9 ± 5.57	4.39 ± 2.11	3.44 ± 1.66	3.07 ± 1.47
Dagana	11.17 ± 6.03	4.36 ± 2.49	3.79 ± 2.11	3.06 ± 1.84
Gasa	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Haa	4.8 ± 4.1	2.49 ± 1.95	1.2 ± 1.14	1.29 ± 1.18
Lhuntse	15.65 ± 6.65	6.11 ± 2.41	5.27 ± 2.68	3.98 ± 1.81
Mongar	10.11 ± 5.01	3.49 ± 1.67	3.44 ± 1.77	3.08 ± 1.54
Paro	2.02 ± 2.24	1.01 ± 1.13	0.63 ± 0.66	0.4 ± 0.45
Pemagatshel	4.63 ± 3.35	2.08 ± 1.53	1.26 ± 0.91	1.29 ± 1.01
Punakha	4.92 ± 3.67	2.49 ± 1.73	1.52 ± 1.17	1.04 ± 0.86
Samdrupjongkhar	11.77 ± 5.01	4.44 ± 2.1	3.95 ± 1.83	3.2 ± 1.48
Samtse	6.34 ± 4.3	2.71 ± 1.98	1.98 ± 1.26	1.53 ± 1.19
Sarpang	10.08 ± 4.51	4.04 ± 1.92	3.19 ± 1.61	2.5 ± 1.36
Thimphu	5.62 ± 4.29	1.75 ± 1.25	2.33 ± 1.92	1.47 ± 1.14
Trashigang	16.39 ± 6.16	6.9 ± 2.54	5 ± 2.03	4.4 ± 2.11
Trashiyangtse	11.08 ± 6.94	4.39 ± 3.16	3.32 ± 2.17	3.47 ± 2.42
Trongsa	12.43 ± 6.57	5.05 ± 2.79	3.95 ± 2.19	3.48 ± 2.24
Tsirang	9.02 ± 10.13	4.61 ± 5.66	1.99 ± 2.33	2.29 ± 2.45
Wangduephodrang	9.94 ± 4.84	4.45 ± 2.34	3.18 ± 1.64	2.49 ± 1.47
Zhemgang	13.67 ± 5.5	5.14 ± 2.04	4.4 ± 1.86	4.24 ± 1.79

Table 27: Soil organic carbon density estimates (tonnes per hectare) by Dzongkhag with ± margin of error at 90% confidence level

Dzongkhag	0-30 cm	0-10cm	10-20cm	20-30cm
Bumthang	76.262 ± 9.723	29.014 ± 5.356	27.126 ± 5.377	20.38 ± 3.386
Chhukha	59.924 ± 12.286	23.889 ± 5.537	18.594 ± 4.276	16.834 ± 3.507
Dagana	70.47 ± 19.236	27.94 ± 7.112	23.634 ± 6.714	19.177 ± 6.712
Gasa	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Haa	54.506 ± 24.173	27.994 ± 12.111	13.671 ± 7.428	14.468 ± 9.632
Lhuntse	72.415 ± 13.019	27.766 ± 4.57	24.13 ± 8.285	17.918 ± 4.773
Mongar	54.538 ± 11.483	19.007 ± 5.391	18.659 ± 5.355	16.885 ± 4.754
Paro	46.47 ± 18.266	22.55 ± 9.57	13.975 ± 4.318	8.674 ± 5.364
Pemagatshel	44.842 ± 17.519	20.497 ± 8.156	12.357 ± 5.456	12.598 ± 4.661
Punakha	55.24 ± 19.35	27.655 ± 8.592	16.282 ± 7.217	11.46 ± 5.356
Samdrup Jongkhar	50.787 ± 10.907	19.614 ± 4.715	17.148 ± 4.393	13.98 ± 3.374
Samtse	55.605 ± 17.31	23.988 ± 9.641	17.218 ± 4.587	13.132 ± 7.484
Sarpang	48.429 ± 9.374	20.843 ± 3.691	16.07 ± 4.352	12.482 ± 4.191
Thimphu	70.696 ± 16.139	22.133 ± 5.073	29.868 ± 8.348	18.613 ± 6.723
Trashigang	67.57 ± 10.849	28.424 ± 4.474	20.578 ± 4.404	18.55 ± 4.548
Trashiyangtse	98.29 ± 25.68	38.646 ± 16.294	29.584 ± 6.702	30.783 ± 10.955
Trongsa	79.135 ± 18.46	31.986 ± 6.58	24.834 ± 7.157	22.139 ± 8.121
Tsirang	197.28 ± 106.953	102.272 ± 73.405	45.688 ± 24.493	51.212 ± 29.042
Wangduephodrang	55.163 ± 10.075	24.264 ± 6.158	17.336 ± 4.083	13.604 ± 4.66
Zhemgang	52.379 ± 7.225	19.453 ± 3.931	16.752 ± 3.078	15.974 ± 3.384

Table 28: Total Soil Organic Carbon estimates (in million tonnes) by Forest type with ± margin of error at 90% confidence level

Forest Type	0-30 cm	0-10cm	10-20cm	20-30cm
Subtropical Forest	9.72 ± 3.71	3.87 ± 1.49	2.93 ± 1.54	2.51 ± 1.13
Warm Broad-leaved Forest	45.54 ± 9.53	17.89 ± 3.74	14.35 ± 3.04	13.33 ± 2.98
Chirpine Forest	4.82 ± 3.99	2.49 ± 2.4	1.15 ± 0.79	1.06 ± 0.81
Cool Broad-leaved Forest	74.24 ± 14.24	30.41 ± 5.32	24.06 ± 4.47	20 ± 4.22
Evergreen Oak Forest	0.98 ± 1.96	0.52 ± 1.05	0.26 ± 0.51	0.2 ± 0.41
Blue Pine Forest	8.06 ± 9.07	3.93 ± 5.27	2.43 ± 2.1	1.68 ± 1.85
Spruce Forest	4.03 ± 3.72	1.78 ± 1.54	1.3 ± 1.34	0.87 ± 0.74
Hemlock Forest	8.15 ± 5.13	3.29 ± 2.11	2.82 ± 1.84	2.06 ± 1.27
Fir Forest	22.76 ± 7.47	9 ± 3.33	7.42 ± 2.39	6.33 ± 2.21
Juniper-Rhododendron Scrub	4.07 ± 3.99	1.58 ± 1.86	1.51 ± 1.48	1.14 ± 1.04

Table 29: Soil Organic Carbon density (tonnes per hectare) by Forest type with ± margin of error at 90% confidence level

Forest Type	0-30 cm	0-10cm	10-20cm	20-30cm
Subtropical Forest	36.604 ± 5.284	15.451 ± 2.154	11.693 ± 2.995	2.095858796
Warm Broad-leaved Forest	54.91 ± 6.112	21.482 ± 2.717	17.181 ± 1.963	2.526570988
Chirpine Forest	38.032 ± 21.151	20.127 ± 14.699	9.127 ± 4.457	4.81786014
Cool Broad-leaved Forest	73.926 ± 6.34	30.163 ± 2.76	23.929 ± 2.644	2.391867805
Evergreen Oak Forest	85.16 ± 0	45.22 ± 0	22.18 ± 0	0
Blue Pine Forest	87.478 ± 81.877	42.834 ± 47.928	26.627 ± 17.138	16.12791288
Spruce Forest	60.267 ± 18.836	26.904 ± 9.011	18.955 ± 13.102	4.60375
Hemlock Forest	72.266 ± 12.585	28.841 ± 8.542	25.128 ± 6.393	4.245886905
Fir Forest	73.35 ± 6.874	28.867 ± 4.132	23.736 ± 3.319	3.674416571
Juniper-Rhododendron Scrub	74.824 ± 39.359	29.17 ± 19.227	26.632 ± 14.62	9.837291667

Table 30: Total Soil Organic Carbon estimates (in million tonnes) for broadleaf and conifer forest with ± margin of error at 90% confidence level

Major forest type	0-30 cm	0-10cm	10-20cm	20-30cm
Broadleaf forest	134.35 ± 16.09	54.56 ± 7.78	42.26 ± 4.73	37.23 ± 5.19
Coniferous forest	50.09 ± 10.55	20.58 ± 4.46	16.4 ± 3.74	12.54 ± 2.86

Table 31: Soil Organic Carbon density estimates (tonnes per hectare) for broadleaf and conifer forest with ± margin of error at 90% confidence level

Major forest type	0-30 cm	0-10cm	10-20cm	20-30cm
Broadleaf forest	64.441 ± 5.917	26.376 ± 2.765	20.404 ± 1.807	17.973 ± 1.85
Coniferous forest	65.981 ± 6.053	26.919 ± 3.439	21.509 ± 2.699	16.645 ± 2.086

Table 32: Total Soil Organic Carbon estimates (in million tonnes) by elevation with ± margin of error at 90% confidence level

Elevation range	Soil 0-30	Soil 0-10	Soil 10-20	Soil 20-30
Less than 1000 m	17.43 ± 5.88	7.77 ± 2.72	4.83 ± 1.61	4.49 ± 1.49
1000-2000 m	60.38 ± 13.78	24.79 ± 6.95	18.75 ± 3.77	16.6 ± 3.72
2000-3000 m	66.59 ± 12.63	26.84 ± 5.27	21.44 ± 4.61	18.08 ± 3.95
3000-4000 m	42.4 ± 9.65	16.48 ± 4.34	14.39 ± 3.43	11.46 ± 2.74

Table 33: Soil Organic Carbon density estimates (tonnes per hectare) by elevation with ± margin of error at 90% confidence level

Elevation range	Soil 0-30	Soil 0-10	Soil 10-20	Soil 20-30
Less than 1000 m	38.734 ± 7.2	17.864 ± 4.271	11.024 ± 1.593	9.934 ± 2.157
1000-2000 m	61.758 ± 9.448	25.295 ± 5.644	19.092 ± 2.55	16.912 ± 2.764
2000-3000 m	76.835 ± 6.849	30.953 ± 3.204	24.873 ± 2.88	20.994 ± 2.566
3000-4000 m	68.07 ± 6.706	26.477 ± 3.054	22.881 ± 3.076	18.475 ± 2.37

APPENDIX 3:
SPECIES DIVERSITY

Table 34: Measures of tree species diversity

Category	Shannon Diversity Index(H)	Simpson's diversity	Evenness	Alpha	Gamma	β-diversity	Observed	Extrapolated(Jackknife)	SE for Extrapolated
Country	1.05	0.53	0.17	4.23	463	458.77	463	0.99	8.94

Table 35: Measures of tree species diversity for forest and non-forest

Category	Shannon Diversity Index(H)	Simpson's diversity	Evenness	Alpha	Gamma	β-diversity	Observed	Extrapolated(With Jacknife)	SE for Extrapolated
Forest	1.15	0.58	0.19	4.59	448	96.65	448	527	9.43
Non-forest	0.51	0.28	0.09	2.32	250	106.83	250	336	11.3

Table 36: Measures of tree species diversity by Dzongkhag

Dzongkhag	Shannon Diversity Index(H)	Simpson's diversity	Evenness	Alpha	Gamma	β-diversity	Observed	Extrapolated(With Jacknife)	SE for extrapolated
Bumthang	0.76	0.41	0.19	3.13	56	16.91	56	2	3.72
Chhukha	1.2	0.61	0.23	4.58	185	39.36	185	2	9.76
Dagana	1.38	0.66	0.26	5.52	209	36.88	209	2	9.18
Gasa	0.85	0.47	0.23	3.17	43	12.55	43	2	6.22
Haa	1.03	0.54	0.21	4.02	137	33.09	137	2	10.05
Lhuntse	1.12	0.58	0.24	4.27	103	23.13	103	2	7.03
Mongar	1.12	0.56	0.22	4.58	155	32.81	155	2	9.08
Paro	0.78	0.44	0.2	3.05	52	16.03	52	2	5.06
Pemagatshel	1.31	0.64	0.27	5.39	135	24.03	135	2	8.55
Punakha	1.25	0.61	0.27	5.07	101	18.92	101	2	7.22
Samdrupjongkhar	1.42	0.67	0.27	5.86	190	31.4	190	2	9.18
Samtse	1.18	0.6	0.24	4.36	145	32.24	145	2	7.95
Sarpang	1.53	0.71	0.29	6.1	207	32.96	207	2	8.56
Thimphu	0.69	0.39	0.18	2.83	44	14.57	44	2	5.62
Trashigang	1.08	0.54	0.21	4.64	158	33.04	158	2	7.39
Trashiyangtse	1.1	0.59	0.25	3.95	84	20.25	84	2	7.56
Trongsa	1.19	0.61	0.25	4.59	127	26.69	127	2	8.26
Tsirang	1.37	0.63	0.28	6.06	144	22.75	144	2	12.34
Wangduephodrang	1.03	0.54	0.2	4.01	158	38.4	158	2	10.37
Zhemgang	1.32	0.65	0.24	5.12	220	42.01	220	2	9.24

Table 37: Measures of species diversity for forest type categorized in Broadleaf forest and Conifer forest

Major forest category	Shannon Diversity Index(H)	Simpson's diversity	Evenness	Alpha	Gamma	β-diversity	Observed	Extrapolated (With Jacknife)	SE for extrap-olated
Broadleaf	1.33	0.65	0.22	5.27	426	420.73	426	506	9.64
Conifer	0.75	0.41	0.15	3.02	164	160.98	164	227	9.48

Table 38: Measures of species diversity by elevation range

Elevation range	Shannon Diversity Index(H)	Simpson's diversity	Evenness	Alpha	Gamma	β-diversity	Observed	Extrapolated (With Jacknife)	SE for extrapolated
Less than 1000 m	1.33	0.63	0.24	5.38	258	46.97	258	317	8.87
1000-2000 m	1.26	0.62	0.22	5.03	339	66.35	339	422	9.74
2000-3000 m	1.2	0.61	0.22	4.76	267	55.04	267	331	8.94
3000-4000 m	0.83	0.46	0.18	3.24	104	31.09	104	130	5.09
4000 m +	0.21	0.13	0.12	1.43	6	3.2	6	8	1.35

APPENDIX 4:
REGENERATION

**Count refers to number of individuals.*

Table 39: Total Regeneration Count(in millions) estimates with ± margin of error at 90% confidence level for Forest and non-forest

Category	Recruits	Unestablished	Established
Forest	2349±541	2123±327	3916±491
Non-forest	330±294	457±226	1277±636

Table 40: Per hectare regeneration count for forest and non-forest with ± margin of error at 90% confidence level

Category	Recruits	Unestablished	Established
Forest	746±169	674±101	1240±155
Non-forest	478±432	666±316	1889±840

Table 41: Total Regeneration Count (in millions) estimates by Dzongkhag with ± margin of error at 90% confidence level

Category	Recruits	Unestablished	Established
Bumthang	422±201	85±45	97±46
Chhukha	27±31	45±22	89±32
Dagana	105±46	112±45	273±82
Gasa	88±151	28±22	37±40
Haa	107±82	166±94	283±172
Lhuntse	76±54	80±47	213±99
Mongar	51±39	54±29	172±70
Paro	49±51	127±136	152±169
Pemagatshel	7±9	7±9	34±33
Punakha	140±187	149±116	261±222
Samdrupjongkhar	46±29	74±32	229±66
Samtse	26±14	52±20	249±276
Sarpang	38±21	79±48	130±49
Thimphu	111±91	67±36	145±73
Trashigang	269±181	134±80	245±115
Trashiyangtse	142±117	123±75	111±58
Trongsa	78±45	69±36	155±63
Tsirang	32±34	78±63	87±46
Wangduephodrang	384±405	378±234	554±253
Zhemgang	84±56	159±76	322±90

Table 42: Per hectare regeneration count by Dzongkhag with ± margin of error at 90% confidence level

Category	Recruits	Unestablished	Established
Bumthang	2221±870	443±208	513±198
Chhukha	209±230	353±121	701±141
Dagana	429±182	453±152	1119±275
Gasa	1878±3099	636±322	865±738
Haa	724±517	1146±519	1929±1001
Lhuntse	732±460	767±357	2060±658
Mongar	323±239	336±163	1079±313
Paro	732±670	1924±1471	2248±2311
Pemagatshel	159±191	161±154	735±598
Punakha	1222±1412	1240±873	2268±1555
Samdrupjongkhar	232±129	366±122	1150±205
Samtse	182±84	364±105	1788±1790
Sarpang	171±79	360±178	574±188
Thimphu	874±681	527±222	1130±473
Trashigang	970±678	492±264	902±365
Trashiyangtse	1246±860	1075±517	964±374
Trongsa	527±258	475±198	1064±303
Tsirang	330±301	792±611	882±388
Wangduephodrang	1293±1340	1280±748	1875±804
Zhemgang	301±186	569±216	1142±232

Table 43: Total regeneration count(in millions) by forest type with ± margin of error at 90% confidence level

Category	Recruits	Unestablished	Established
Subtropical Forest	55±26	97±46	437±105
Warm Broad-leaved Forest	174±59	394±126	786±204
Chirpine Forest	56±41	31±26	71±36
Cool Broad-leaved Forest	625±154	708±123	1421±327
Evergreen Oak Forest	73±93	83±78	138±195
Blue Pine Forest	256±154	102±65	200±102
Spruce Forest	57±82	31±48	83±139
Hemlock Forest	257±411	153±216	150±121
Fir Forest	716±289	457±184	506±269
Juniper-Rhododendron Scrub	49±43	42±42	65±42

Table 44: Per hectare regeneration count by forest types with ± margin of error at 90% confidence level

Category	Recruits	Unestablished	Established
Subtropical Forest	150±63	268±111	1201±207
Warm Broad-leaved Forest	258±77	581±175	1158±272
Chirpine Forest	500±328	274±217	620±235
Cool Broad-leaved Forest	535±126	606±91	1211±274
Evergreen Oak Forest	1330±1552	1486±1095	2439±3103
Blue Pine Forest	1724±950	678±385	1355±555
Spruce Forest	1317±1731	702±1047	1748±3165
Hemlock Forest	2681±3670	1636±1886	1555±992
Fir Forest	1774±650	1125±430	1248±601
Juniper-Rhododendron Scrub	645±577	571±479	887±496

Table 45: Total regeneration count(in millions) in broadleaf and conifer forest with ± margin of error at 90% confidence level

Forest type	Recruits	Unestablished	Established
Broadleaf forest	929±183	1282±179	2724±399
Coniferous forest	1384±523	783±285	1094±318

Table 46: Per hectare regeneration count in broadleaf and conifer forest with ± margin of error at 90% confidence level

Forest type	Recruits	Unestablished	Established
Broadleaf forest	426±83	587±79	1246±171
Coniferous forest	1583±578	890±324	1241±335

Table 47:Total regeneration count (in millions) by elevation range with ± margin of error at 90% confidence level

Elevation Range	Recruits	Unestablished	Established
Less than 1000 m	89±31	160±53	551±129
1000-2000 m	281±72	450±125	1102±347
2000-3000 m	1051±460	897±241	1397±286
3000-4000 m	914±313	599±192	819±296
4000 m +	0±0	8±10	21±33

Table 48: Per hectare regeneration count by elevation with ± margin of error at 90% confidence level

Elevation Range	Recruits	Unestablished	Established
Less than 1000 m	188±62	346±97	1188±180
1000-2000 m	318±75	509±137	1256±372
2000-3000 m	952±389	808±196	1259±214
3000-4000 m	1354±404	878±287	1197±414
4000 m +	0±0	549±450	1374±1811

Table 49: Total regeneration count (in millions) by species with ± margin of error at 90% confidence level

Species	Recruits	Unestablished	Established
Abies densa	462±210	243±134	109±42
Acer	106±52	59±23	83±32
Ailanthus integrifolia	0±0	0±0	1±2
Alnus	0±0	1±2	8±12
Aphanamixis polystachya	4±6	6±9	7±11
Beilschmiedia	25±49	16±16	32±25
Betula	5±5	5±6	2±3
Castanopsis	65±28	112±53	215±69
Duabanga grandiflora	0±0	0±0	2±4
Engelhardtia spicata	2±3	4±5	7±8
Juniperus	39±68	14±11	20±15
Larix griffithii	0±0	1±2	0±0
Magnolia	1±2	3±6	9±13
Persea	43±21	71±26	124±42
Picea spinulosa	49±85	2±2	25±18
Pinus roxburghii	58±39	19±16	40±34
Pinus wallichiana	207±148	49±33	123±68
Quercus	155±76	131±37	258±69
Rhododendron	177±69	283±83	551±226
Schima wallichii	6±6	29±18	67±34
Sterculia vilosa	0±0	1±2	1±2
Tsuga dumosa	22±22	29±22	25±32
Others	884±446	1017±271	2184±438

Table 50: Per hectare regeneration count by species with ± margin of error at 90% confidence level

Species	Recruits	Unestablished	Established
Abies densa	1745±756	924±474	414±144
Acer	521±234	293±98	418±112
Ailanthus integrifolia	0±0	0±0	250±0
Alnus	0±0	83±167	812±687
Aphanamixis polystachya	333±416	583±416	666±583
Beilschmiedia	397±728	250±210	500±304
Betula	178±121	167±208	71±78
Castanopsis	227±76	387±164	736±181
Duabanga grandiflora	0±0	0±0	500±0
Engelhardtia spicata	83±93	167±167	333±250
Juniperus	618±1006	232±136	315±184
Larix griffithii	0±0	250±0	0±0
Magnolia	42±83	107±268	428±446
Persea	394±193	454±113	971±187
Picea spinulosa	192±72	310±94	552±131
Pinus roxburghii	1119±1942	38±54	574±237
Pinus wallichiana	970±492	319±180	687±429
Quercus	1499±953	351±229	893±410
Rhododendron	382±177	323±78	636±131
Schima wallichii	361±132	578±150	1121±426
Sterculia vilosa	50±66	285±161	669±274
Tsuga dumosa	0±0	125±125	125±125
Others	479±474	656±308	566±599

APPENDIX 5:
ANNUAL INCREMENT

Table 51: Annual Basal area increment for forest and non-forest with ± margin of error at 90% confidence level

Category	BAI per hectare/year (m^2)
Forest	0.48±0.05
Non-forest	0.27±0.08

Table 52:Annual Basal area increment(BAI) by Dzongkhag with ± margin of error at 90% confidence level

Dzongkhags	BAI per hectare/year (m^2)
Bumthang	0.44±0.12
Chhukha	0.69±0.45
Dagana	0.35±0.12
Gasa	0.13±0.15
Haa	0.35±0.23
Lhuntse	0.66±0.26
Mongar	0.5±0.15
Paro	0.32±0.17
Pemagatshel	0.62±0.33
Punakha	0.68±0.77
Samdrupjongkhar	0.51±0.13
Samtse	0.69±1.42
Sarpang	
Thimphu	
Trashigang	0.47±0.13
Trashiyangtse	0.21±0.08
Trongsa	0.34±0.22
Tsirang	
Wangduephodrang	0.27±0.1
Zhemgang	0.53±0.12

Table 53:Annual Basal area increment(BAI) in broadleaf and conifer forest with ± margin of error at 90% confidence level

Major forest type	BAI per hectare/year (m^2)
Broadleaf forest	0.51±0.06
Coniferous forest	0.41±0.12

Table 54: Annual Basal area increment (BAI) by elevation range with ± margin of error at 90% confidence level

Elevation Range	BAI per hectare/year (m^2)
Less than 1000 m	0.49±0.11
1000-2000 m	0.57±0.1
2000-3000 m	0.47±0.09
3000-4000 m	0.35±0.11
4000 m +	Not recorded

Table 55: Annual Basal area increment by forest type with ± margin of error at 90% confidence level

Forest type	BAI per hectare/year (m^3)
Subtropical Forest	0.44±0.11
Warm Broad-leaved Forest	0.61±0.12
Chirpine Forest	0.46±0.07
Cool Broad-leaved Forest	0.31±0.12
Evergreen Oak Forest	0.12±0
Blue Pine Forest	0.82±0.78
Spruce Forest	0.47±0.51
Hemlock Forest	0.58±0.53
Fir Forest	0.3±0.09
Juniper-Rhododendron Scrub	0.12±0.1

Table 56: Annual basal area increment by species with ± margin of error at 90% confidence level

Species	BAI per hectare/year (m^2)
Abies densa	0.04 ±0.01
Acer sp.	0.02 ±0.01
Ailanthus integrifolia	0.02 ±0
Alnus sp.	0.11 ±0.05
Aphanamixis polystachya	0.03 ±0
Beilschmiedia	0.03 ±0.01
Betula sp.	0.04 ±0.02
Castanopsis sp.	0.05 ±0.01
Duabanga grandiflora	0.16 ±0.09
Engelhardtia spicata	0.06 ±0.03
Juniperus sp.	0.02 ±0.01
Magnolia sp.	0.03 ±0.01
Persea sp.	0.04 ±0.01
Picea spinulosa	0.04 ±0.02
Pinus roxburghii	0.07 ±0.01
Pinus wallichiana	0.12 ±0.13
Quercus sp.	0.05 ±0.01
Rhododendron	0.02 ±0
Schima wallichii	0.03 ±0.01
Symplocos cochinchinensis	0.04 ±0.01
Tetrameles nudiflora	0.13 ±0.22
Tsuga dumosa	0.07 ±0.03
Others	0.07 ±0.01

Table 57: Annual Above ground biomass increment (AGBI) for forest and non-forest with ± margin of error at 90% confidence level

Category	AGBI per hectare/year (t/ha)
Forest	2 ±0.22
Non-forest	1 ±0.42

APPENDIX 6:
BIOMASS MODELS

Table 58: Allometric biomass models

Sl. No	Species	Equations	t1	t2	t3
1	*Abies densa*	(-5.76+3436.38*ba+36408.9*X2)	0.004562064	0.110446617	0.303648
2	*Alnus nepalensis*	(-12.3+5474*ba+1581*X2)	0.008812246	0.131185153	0.415138
3	*Castanopsis tribulnoides*	1.39+5303*ba+2722*X2+4129*X3	0.007382271	0.134038	0.40222
4	*Cupressus corneyana*	(-3.96+4300*ba+50295*X2)	0.003904686	0.098999438	0.37853
5	*Juniperus recurva*	(-4.85+3234*ba+26753*X2)	0.006816078	0.075555303	0.263935
6	*Larix griffithii*	(-3.84+3455*ba+29738*X2)	0.008395906	0.131147749	0.330317
7	*Picea spinulosa*	(-6.164+3934*ba+43569*X2)	0.00664761	0.11341149	0.321234
8	*Pinus roxburghii*	(-3.44+5098*ba+56376*X2)	0.0023	0.1029	0.368529
9	*Pinus wallichiana*	(-1.57+3444*ba+55392*X2)	0.00309	0.09840699	0.394911
10	*Quercus glauca*	(-3.97+6437*ba+36970*X2)	0.006535691	0.099043421	0.374257
11	*Quercus griffithii*	(-9.38+5438*ba+15835*X2)	0.007310172	0.1321385	0.364998
12	*Quercus lanata*	(-0.77+4500*ba+25308*X2)	0.01333473	0.1418822	0.393956
13	*Rhododendron arboreum*	(-0.19+1637*ba+43190*X2)	0.006834221	0.09186331	0.207339
14	*Tsuga dumosa*	(-4.8+3854*ba+15174*X2)	0.006180612	0.138544236	0.440845
15	*General broadleaf*	(-1.06+4341*ba+30173*X2+4013*X3)	0.00664761	0.1194591	0.368977
16	*General conifer*	(-12.3+3299*ba+52756*X2)	0.004927274	0.107521009	0.369822

$$g(X_1) = (X_1 - t_1)_+^3 - (X_1 - t_2)_+^3 \left(\frac{t_3 - t_1}{t_3 - t_2}\right) + (X_1 - t_3)_+^3 \left(\frac{t_2 - t_1}{t_3 - t_2}\right)$$

Technical note about spline transformation: $X_2 = g(X_1)$

In the right side of the expression for $g(X_1)$, the parenthesized terms followed by a $+$ are known as positive-part functions, and are to be interpreted as follows:

$$(X_1 - t_1)_+^3 = \begin{cases} 0, \text{ if } X_1 < t_1 \\ (X_1 - t_1)^3, \text{ if } X_1 \geq t_1 \end{cases}$$

$$(X_1 - t_2)_+^3 = \begin{cases} 0, \text{ if } X_1 < t_2 \\ (X_1 - t_2)^3, \text{ if } X_1 \geq t_2 \end{cases}$$

$$(X_1 - t_3)_+^3 = \begin{cases} 0, \text{ if } X_1 < t_3 \\ (X_1 - t_3)^3, \text{ if } X_1 \geq t_3 \end{cases}$$

Note on spline term usage:

$X_2 = g(X_1)$

X_3 = 1/0, indicator variable for forked trees

t_1, t_2, t_3 = knot values at 10^{th}, 50^{th} and 90^{th} quantile

ANNEXURE I:
LIST OF NATIONAL FOREST INVENTORY TEAM MEMBERS

a. NFI Coordination Team

Sl.	Name	Designation	Office
1	Lobzang Dorji	Chief Forestry Officer (2014-)	FRMD
2	Dr. D.B Dhital	Chief Forestry Officer (2009)	FRMD
3	Kinley Tshering	Chief Forestry Officer (2009-2014)	FRMD
4	Kezang Yangden	Dy. Cheif Forestry Officer	FRMD
5	Younten Phuntsho	Sr. Forestry Officer	FRMD
6	Santosh Katwal	Sr. Forestry Officer	FRMD
7	Ugyen Penjor	Forestry Officer (2015-2016)	FRMD
8	Dorji Wangdi	Dy. Cheif Forestry Officer (2016-)	FRMD

b. NFI Core Team (Advisory)

Sl.	Name	Designation	Office
1	Secretary		MOAF
2	Director		DoFPS
3	Chief Forestry Officer(s)		FRMD, SFED, FPED, WCD, NRED, WMD
4	Thinley Namgyel	Chief Environment Officer	NECS
5	Chukey Wangchuk	Chief Program Officer (2009-2015)	BTFEC
6	Rebecca Pradhan	Ecologist	RSPN
7	Rinchen Yangzom	Dy. Chief Biodiversity Officer	NBC
8	Representative from NSSC		

c. NFI Crew

Sl.	Name	Designation	Office
1	Late Langa Tshering	Sr. Forest Ranger (Crew Leader)	Gedu Division
2	Kezang Dorji	Sr. Forest Ranger	Samtse Division
3	Karma Tenzin	Forest Ranger	Gedu Division
4	Basant Thapa	Forester	Gedu Division
5	I K Bhujel	Forester	Samtse Division
6	Tashi	Sr. Forest Ranger (Crew Leader)	Paro Division
7	Tshering Wangchuk	Forester	Paro Division
8	Tshering Phuntsho	Forester	Wangdue Division
9	Tashi Phuntsho	Forester	Wangdue Division
10	Tenzin Dorji	Sr. Forester	Wangdue Division
11	Tenzin Jamtsho	Forest Ranger (Crew Leader)	Paro Division
12	Nidup Dorji	Forest Ranger	Paro Division
13	Phurpa Tshering	Sr. Forester	Paro Division
14	Tularam Suberi	Forester	Sarpang Division
15	Guman Singh Biswa	Forester	JKSNR
16	Jamyang Tenzin	Sr. Forest Ranger (Crew Leader)	UWICE
17	Kezang Phuntsho	Sr. Forester	Thimphu Division
18	Dorji Wangchuk	Forester	Thimphu Division
19	Sonam Wangpo	Forester	Thimphu Division
20	Changala	Forester	Thimphu Division
21	Sonam Wangdi	Sr. Forest Ranger (Crew Leader)	RMNP
22	Rinchen Dorji	Forester	RMNP
23	Singye	Forester	RMNP
24	Phurba Dorji	Forester	Zhemgang Division
25	Harkey Ghalley	Forester	Zhemgang Division
26	Yeshey Nidup	Sr. Forest Ranger (Crew Leader)	WCNP
27	Tandin Wangchuk	Forester	PNP
28	Chimi Tshewang	Forester	JSWNP
29	Sangay Tshering	Sr. Forester	JSWNP
30	Sangay Penjor	Forester	JDNP
31	Gyeltshen	Forester	Tsirang Division
32	Dawa Wangdi Sherpa	Forester	Tsirang Division
33	Sangay Lhajay	Sr. Forester	Sarpang Division
34	Dorji Dukpa	Forester	Sarpang Division
35	Tashi Tobgay	Forest Ranger (Crew Leader)	JDNP
36	Gembo Tshering	Forester	Mongar Division
37	Dawa Norbu	Forester	Mongar Division
38	Rinchen Khandu	Forest Ranger (Crew Leader)	SWS
39	Lhakpa Tshering	Sr. Forest Ranger	BWS
40	Tashi Dorji	Forester	JDNP

41	Tshering Wangchuk	Forester	JSWNP
42	Rinchen Dorji	Forester	Trashigang Division
43	Phurpa Dorji	Sr. Forester (Crew Leader)	SWS
44	Nidup Dorji	Forester	Trashigang Division
45	Chedup	Forester	Trashigang
46	Pema Namgyal	Forester	SWS
47	Tenzin Rabgay	Forest Ranger (Crew Leader)	JDNP
48	Karma Nidup	Forest Ranger	Samdrup Jongkhar Division
49	Karman Subba	Sr. Forester	Samdrup Jongkhar Division
50	Karma Gyeltshen	Forester	JDNP
51	Namgay Dorji	Forester	JDNP
52	Late Wangchuk	Forest Ranger (2012-2014)	Samdrup Jongkhar Division
53	DB Chettri	Sr. Forest Ranger (2012-2014)(Crew Leader)	Tsirang Division
54	Sonam Drupchu	Forest Ranger (2012-2014) (Crew leader)	Mongar Division
55	Phuntsho	Forest Ranger (2012-2014) (Crew leader)	SWS
56	Karma Dorji	Forest Ranger (2012-2014) (Crew leader)	Wangdue Division
57	Lha Tshering	Forest Ranger (2012-2015) (Crew leader)	Mongar Division

d. NFI Data Management and Analysis Team for NFI Vol II

Sl.	Name	Designation	Office
1	Kezang Yangden	Dy. Cheif Forestry Officer	FRMD
2	Younten Phuntsho	Sr. Forestry Officer	FRMD
3.	Dorji Wangdi	Dy. Cheif Forestry Officer	FRMD
4.	Kinley Dem	Sr. Forestry Officer	FRMD
5.	Dr. Jigme Tenzin	Dy. Cheif Forestry Officer	WMD
6.	Ugyen Penjor	Sr. Forestry Officer	NCD

e. External Experts for Data management and Analysis

Sl.	Name	Designation	Office
1	Javier Garcia Perez	Forest Statistician	FAO, ROME
2	Stefano Ricci	Software Engineer	FAO, ROME
3	Cosimo Togna	Forestry Officer	FAO, ROME
3	Timothy G. Gregoire	Professor	Yale FES

ANNEXURE II:
FOREST TYPE

Sl.No	Forest Type	Code	Characteristics	Characteristic species
1	Subtropical Forest	STFr	· Contain many tropical genera and species, forming dense jungle · Scattered Sal trees in Sarbang areas · **Altitudinal range: 200-1000 m (-1200m)**	*Acraocarpus fraxinifolius, Ailanthus grandis, Bombax ceiba, Crateva regiliosa, Dellinia pentgyna, Duanbanga grandiflora. Gmelina arborea, Leea asiatica, Musa, Pnadanus, Pterospermum acerifiolium, Shorea robusta, Tetremeles nudiflora, Thunbergia*
2	Warm Broad-leaved Forest	WBFr	· Type of Subtropical forest, but occurs at higher altitude with lower rainfall · Contains mixture of Evergreen and deciduous broad leaved species · Many of the tropical genera e.g. Duabanga, Pterospermum and Tetrameles are absent · **Altitudinal range: 1000-2000m(-2300m)**	*Alangium chinensis, Altingia excels,Bischofia javanica Calicarpa arborea, Castanopsis indica, Cordia oblique, Dendrocalamus hookeri Dichroa febrifuga, Engelhardia spicata, Eoudia fraxinifolia, Macaranga pustulata, Maesa spp., Mussaenda roxburghii, Pouzolzia sanguine, Raphidophora eximea, Schima wallichi, Wandlandia puberula*
3	Chirpine Forest	CPFr	· Low-altitude xerophytic forest occurring in the deeper dry valleys of Bhutan · Almost no other tree species occur in such forest other than Chirpine · **Altitudinal range:900-1800 m(-2000m)**	*Buddleja asiatica, B.bhutanica, Cycas pectinata, Cymbopogon flexuosus, Euphobia royleana, Ficus obligodon, Grewia sapida Indigofera dosua, Rhus paniculata, Zizyphus incurve*
4	Cool Broad-leaved Forest	CBFr	· Found on moist exposed slopes · Mixed forest in which oaks are LESS COMMON and other trees, both deciduous and evergreen, e.g. Lauraceae, Exbucklandia etc., are more abundant together with dense shrubs, climbers and epiphytes · **Altitudinal range:2000-2900m**	*Acer campbelli, A.sterculiaceum, Betula alonoides,Brassiopsis alpine, Chirita lachensis, Corylopsis himalayana, Elatostema monandrum, E. obtusum, Exbucklandia populnea, Ilex fragilis, Lecanthus peduncularis, Lindera neesiana, L.pulcherrima, Persea clarkeana, Pilea bracteosa, Rosa moschata, Rubus lineatus, Schisandra grandiflora, Symplocus dryiphila*

5	Evergreen Oak Forest	EOFr	· Characteristic feature of some parts of Central Bhutan(for e.g. Trongsa and hills above Mongar) · Composition varies according to altitude and rainfall · At lower levels, Castanopsis hystrix and C.tribuloides are often dominant, higher up Quercus lamellose becomes commoner · With increasing dryness , more xerophytic Quercus species,e.g. Q.lanata,Q.grifithii and Q.semicarpifolia and Pinus wallichiana are seen · Not much shrub layer, whilst shady humid floors are dominated by small herbs · **Altitudinal range: (1800-)2000-2600m**	*Acer campbelli, castanopsis hystrix, C. tribuloides, Elatostema hookerianum, E.sessile, Galeola lindleyana,* *Juglans regia, Pilea symmeria, Quercus lamellose, Skimmia arborescens, Symplocus lucida*
6	Blue Pine Forest	BPFr	· Temperate equivalent of Chirpine forest and occupies the dry valleys of Bhutan · Bluepine dominant with Quercus species in some places · Xerophytic shrubs occurs and herbs mostly appear during the monsoon season · **Altitudinal range: 2100-3000(-3200)m**	*Berberis asiatica, Berchemia edgeworthii, Cotoneaster griffithii, Eleagnus parviflora, Euonymus grandiflorus, Indigofera heterantha, Jasminium humile,* *Prinsepia utilis, Lyonia ovalifolia, Quercus griffithii,* *Q.semicarpifolia, Rhododendron arboretum, Rosa sericea, Spirea canescens, Zanthoxylum armatum*
7	Spruce Forest	SPFr	· Spruce forest with Hemlock and Fir forests occupy the montane cloud-forest zone of Bhutan · Often mixed with each other but separate forests can frequently be recognized · Spruce are found at lower altitude than Hemlock and Fir · **Altitudinal range:2700- 3100(-3200)m**	*Acer cappadocicum, A.pectinatum, Berberis praecipua,* *Enkianthus deflexus, Larix grifithiana,* *Lindera heterophylla, Osmanthus suavis,* *Picea brachytyla, P. spinolosa, Salix daltiniana,* *Salvia campanulata, Taxus baccata*
8	Hemlock Forest	HMFr	· Appears at higher altitude than Spruce where Tsuga dumosa is dominant species mixed with Spruce and Fir · Shrubby and arborescent rhododendrons are frequent with dense growth of ferns, lichens and bryophytes · **Altitudinal range: 2800-3100m**	*Arundinaria griffithiana, Betual utilis, Buddleja colvilei, Daphne bholua, Gaultheria fragmentissima, Larix griffithiana, Litsea sericea, Maddenia himalaica, Magnolia globosa, Pnax pseudo-ginseng, Rhododendron falconeri, R.hodgsonis, R. keysii, Rubus calophyllus, R.pentagonus, Sorbus thibetica, Tsuga dumosa, Viburnum mullaha*

9	Fir Forest	FIFr	· Occurs in the greatest ridges of Bhutan below tree line, where huge tracts are covered by no other tree species than Fir (Abies densa) and some Hemlock and Birch in places. · Luxuriant undergrowth of Rhododendrons and other shrubs with many small herbs on mossy ground layer are found. · As tree lines are approached, the firs become stunted and are mixed with Junipers and smaller Rhododendron species · **Altitudinal range: 3300- 3800m**	*Abies densa, Arundinaria maling, Betula utilis, Bryicarpum himalaicum, Daphne bholua, Juniperus pseudosabina, Maddenia himalaica, Primula denticulate, Prunus rufa, Rheum acuminatum, Rhododendron cinnabarinum, R. hodgsonii, Ribes tikare, Rubus fragariodes, Skimmia laureola, Sorbus foliolosa, Viburnum nervosum*
10	Juniper-Rhododendron Scrub	JUSc	· Moist scrub vegetation occurring above treeline throughout Northern and Central Bhutan · Consists of scattered shrubs of Junipers, Rhododendron and Potentilla arbuscula but with rich herb layer appearing during the monsoon · Damp grassy meadow commonly found in this zone · **Altitudinal range: 3700-4200m**	*Gaultheria trichophylla, Juniperus recurva, J.squamata, Morina nepalensis, Pedicularis megalantha, Phlomis tibetica, Potentilla arbuscula, Primula sikkimensis, Rhodendron lepidotum, Thalictrum chelidonii, Trollius purnilus*
11	Dry Alpine Scrub	DASc	· More xerophytic vegetation found · Higher altitude than Juniper-Rhododendron Scrub · **Altitudinal range: 4000-4600m**	*Aconitum orochryseum, Astragalus acaulis, Chesneya nubigena, Cremanthodium thomsonii, Ephedra gerardiana, Meconopsis calderiana, Rheum nobile, Rhododendron anthopogon, Salix lindleyana, Saussurea gossypiphora, S. obvallata, Saxifraga moorcroftiana, Tanacetum gossypinum, Thermopsis barbata*
12	Not sure	NS	· When the data collector is not sure or doesn't know, which category of Forest type to record the plot into, it may be recorded as :"Not Sure"	-

Source: Flora of Bhutan Volume II

ANNEXURE III:
LAND COVER CATEGORY

Sl. No	Land Use Type	Definition	Land cover categories (Reclassified for NFI reporting)
1	Coniferous forests	Forest In which more than 75 percent of tree cover consists of coniferous (Fir, Spruce, Pine) species.	Coniferous forests
2	Broadleaf forests	Forest In which more than 75 percent of tree cover consists of broadleaf and hardwood species.	Broadleaf forests
3	Coniferous plantation	Plantations of more than 75 percent coniferous species	
4	Broadleaf plantation	Plantations of more than 75 percent broadleaf species	Plantation forest
5	Scrub forests	Forest areas characterized by less than 10 percent tree cover; or where vegetations are stunted or dwarfed.	Scrub forests
6	Meadow	Open areas of predominantly grassy vegetation cover and herbaceous plants.	Meadow
7	Chuzhing	Irrigated, bench terraced and land cultivated mainly for rice	
8	Kamzhing	Rainfed, cultivated land which may be terraced or unter-raced.	
9	Mixed agriculture		Agriculture
10	Apple orchard	Self explanatory	
11	Citrus orchard	Self explanatory	
12	Areca nut	Self explanatory	
13	Cardamom Plantation	Self explanatory	
14	Other horticulture		Horticulture
15	Urban	Towns and areas of habitation(near houses but besides roads or other concrete surfaces).	
16	Rural	Areas of habitation in villages (near houses, footpaths, or areas which are not forest, or meadows or agricultural fields)	
17	Impervious surface	Man-made surfaces like roads, concretes, pavements	Settlement
18	Snow/glacier	Only those areas which appear to remain permanently under snow or glacier should be identified as one.	Snow/glacier

19	Rocky outcrop	Areas of rocky outcrop and rocky barren lands, sometimes associated with sparse trees/scrub cover	
20	Scree	Scree, or talus, is accumulation of broken rock fragments at the base of crags, mountain cliffs, or valley shoulders.	Rocky outcrop
21	Lake	A lake is a body of relatively still fresh or salt water of considerable size, localized in a basin, which is surrounded by land apart from a river, stream, or other form of moving water that serves to feed or drain the lake. (Source:en.wikipedia.org/wiki/Lake). Lakes can be Alpine lake, Sub-alpine lakes, Glacier lakes, Supra Glacial lake, Supra snow lake or Tsho.	
22	Reservoir	Any water body held within man-made structure.	
23	River		Water bodies
24	Marshy area	Poorly drained or waterlogged areas of permanent swamp or marsh	Marshy area
25	Landslide	Areas in which there is clear evidence of erosion	
26	Gully	Gullies are vast gaps, crevices created by erosion of soil on hillside by running waters.	
27	Others-		Others

Source: LUPP, 1995