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Acknowledgements

As a continuation of forest resource assessment (FRA) after 2015, the Government of Nepal initiated the remeasurement of FRA permanent sample plots in 2016. Furthermore, additional plots were established and measured in middle mountain of Nepal following the FRA protocols to generate reliable results at the sub-national level.

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Yam Prasad Pokharel
Director General

Abbreviations

AGB	Aboveground Biomass
BGB	Below Ground Biomass
CCSP	Concentric Circular Sample Plot
C	Carbon
CF	Community Forest
DBH	Diameter at Breast Height (1.3 m)
DFRS	Department of Forest Research and Survey
DNPWC	Department of National Parks and Wildlife Conservation
FRA	Forest Resource Assessment
FRTC	Forest Research and Training Centre
GoN	Government of Nepal
KS	Khair-Sissoo
LRMP	Land Resources Mapping Project
MFSC	Ministry of Forests and Soil Conservation
NLCMS	National Land Cover Monitoring System
NTFPs	Non Timber Forest Products
OC	Organic Carbon
OL	Other Land
OWL	Other Wooded Land
PA	Protected Area
PSPs	Permanent Sample Plots
RS	Remote Sensing
SK	Sisoo-Khair
SOC	Soil Organic Carbon
SOP	Standard Operating Procedure
STMH	Sal-Middle Mountain Mixed Hardwood
SVWB	Stem Volume Without Bark
Tg	Teragram (1 Tg = $1X10^{12}$ g)
TMH	Terai Mixed Hardwood
LMH	Lower Mixed Hardwood

Glossary

Aboveground biomass	Aboveground biomass refers to the biomass of trees and saplings (≥5cm DBH) above the soil. It includes deadwood but not stumps.
Belowground biomass	The biomass of trees and saplings (≥5cm DBH) contained within live roots and stumps.
Biomass	The biological material derived from living or recently living organisms. It includes both the above and belowground biomass of trees and saplings.
Broken tree	A tree of which the top or trunk has been cut or broken.
Bulk density	Soil mass per unit volume expressed in g/cm^3.
Canopy	The cover of branches and foliage formed by tree crowns.
Canopy cover/Closure	The percentage of ground covered by the vertical projection of the foliage of plants.
Carbon pool	Major components (Aboveground, belowground, and soil carbon) of carbon per unit area.
Co-dominant	A tree with a medium-sized crown at the level of the general canopy which receives full light from above and at least from one side.
Cull tree	A malformed tree that yields no merchantable logs.
Dead unusable	A dead tree that cannot be used, even as firewood.
Dead usable	A dead tree that can be used as firewood or for another purpose.
Debris	Fallen dead trees and the remains of large branches (<10 cm diameter) on the forest floor
Dominant	A tree whose crown is larger than average and lies at or above the level of the general canopy and receives full light from above and from more than one side.
Dominant species	Species that dominate (comprise > 60% of the basal area) an ecological community (e.g. forest).
Forest	An area of land at least 0.5 ha and a minimum width/length of 20 m with a tree crown cover of more than 10% and tree heights of 5 m at maturity.
Growing stock	The sum of all trees by number or volume or biomass growing within a unit area.
High-quality sound tree	Live tree which will yield saw logs at least 6 m long at present or in the future.
Intermediate	A tree whose crown is smaller than average reaches the general level of the canopy but not above it and receives some direct light from above but little, if any, from the side.
Land cover	The physical material covering the surface of the earth.
Litter	Dead plant materials such as leaves, bark, needles, and twigs that have fallen to the ground.
Non Timber Forest Products	Forest products other than timber.
Other Land	All land that is not classified as Forest or Other Wooded Land.

Other Wooded Land (OWL)	Land not classified as forest spanning more than 0.5 ha, having at least 20 m width, and with a canopy cover of trees between 5% and 10%; trees should be higher than 5 m or able to reach 5 m *in situ*. or The canopy cover of trees less than 5% but the combined cover of shrubs, bushes and trees more than 10%, includingthe area of shrubs and bushes where no trees are present.
Precision	Refers to the size of deviations in estimating a population parameter in the repeated application of a sampling procedure. Standard errors and confidence limits are commonly quoted to quantify precision.
Remote Sensing (RS)	Data acquisition of land surface characteristics, such as total forest area, forest type, canopy cover and height, from sensors aboard aircraft or space-based platforms.
Sal Forest	A forest in which Sal (*Shorea robusta*) comprises more than 60% of the basal area.
Sal Middle Mountain mixed hardwood forest (STMH)	A forest in which Sal comprises 33-60% of the basal area and other associated species are present.
Shrub	An area occupied by woody perennial plants, generally 0.5-5.0 m at maturity and often without definite stems or crowns.
Sound Tree	A live tree not qualified as class 1 but with at least one 3 m saw log or two 1.8 m saw logs.
Stump	The remnant of a cut or fallen tree.
Suppressed	A tree with a smaller crown than normal for a tree of its age and size. It receives little or no direct sunlight and shows signs of retarded growth resulting from competition with dominant trees.
Middle Mountain Mixed Hardwood (TMH)	A forest whose composition in the canopy layer is so mixed that none of the species has over 60% basal area.

Main Results

Forest cover

- Forest and Other Wooded Land (OWL) cover 60.70% (26,11,307 ha) and 3.66% (1,57,408 ha), respectively, of the total area of the Middle Mountain physiographic region (43,02,265 ha). Thus, forest and OWL together cover 64.36% of the total area in the region.

Growing Stock

- The Middle Mountain forest contain a total of 2450.79 million (938.53 per ha) live stems (≥ 5cm DBH). The number of standing dead stems (≥ 5cm DBH) was 80.04 million (30.65 per ha).
- The stem volume for live trees in the Middle Mountain forest is 374.59 million m^3 (143.45 m^3/ha).
- The main tree species in terms of proportion of stem volume are Sal *(Shorea robusta)* with 29.19 m^3/ha, followed by *Pinus roxburghii* with 22.25 m^3/ha.
- The timber volumes without bark up to 10 cm top and up to 20 cm top diameters in the Middle Mountain forest are 91.68 m^3/ha and 66.83 m^3/ha.
- The Middle Mountain forest contained 213.33 t/ha of air-dry biomass, equivalent to 193.94 t/ha of oven-dry biomass.

Carbon stock

- The Middle Mountain forest contain 384.20 million t C (147.13 t/ha) of carbon stock.

Disturbances

- Predominant disturbances are livestock grazing, forest fire, tree cutting and lathra (pole and sapling) cutting.

Executive Summary

This report presents the results of a forest resource assessment carried out in the Middle Mountain physiographic region of Nepal between 2018 and 2020. The forest inventory was conducted from a total of 771 sample plots. Among those, 428 plots (in 147 clusters) were the permanent sample plots (PSPs) established during the Forest Resource Assessment (FRA) 2010/14, which were remeasured in 2018/19. The remaining 343 plots (in 111 clusters) were newly established and measured in 2019/2020. Forest-cover maps were derived from the annual land cover maps prepared using National Land Cover Monitoring System (NLCMS) by Forest Research and Training Center (FRTC). The report mainly consists of information on forest cover, growing stock, carbon stock, and disturbances.

The forest cover mapping shows that out of a total of 4,302,265 ha of land in the Middle Mountain physiographic region, 'forest' and 'other wooded land (OWL)' cover 60.70% (2,611,307 ha) and 3.66% (157,408 ha), respectively. Thus, forest and OWL together cover 64.36% of the total area in the region.

The assessment reveals that the Middle Mountain forest contains a total of 2450.79 million (983.53 per ha) live stems (≥ 5cm DBH). Similarly, the number of standing dead stems (≥ 5cm DBH) is 80.04 million (30.65 per ha). The stem volume in the Middle Mountain forest is 143.45 m^3/ha.

The main tree species in terms of proportion of stem volume are Sal (*Shorea robusta*) with 29.19 m^3/ha, followed by Khote Salla (*Pinus roxburghii*) with 22.25 m^3/ha. The timber volumes without bark up to 10 cm top and up to 20 cm top diameters are 91.68 m^3/ha and 66.83 m^3/ha respectively.

The Middle Mountain forest contain 213.33 t/ha of air-dry biomass, equivalent to 193.94 t/ha of oven-dry biomass. Similarly, it contains 147.13 t/ha of carbon stock. This assessment indicates livestock grazing, forest fire, tree cutting and lathra (pole and sapling) cutting as the most prevalent disturbances in the Middle Mountain forests.

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CHAPTER 1: INTRODUCTION

1.1. Introduction

The Forest Resource Assessment (FRA) Nepal Project (2010-2014) conducted a comprehensive assessment of the Middle Mountain forests between 2010 and 2012 (DFRS, 2014). The project had established 428 permanent sample plots (PSPs) in 147 clusters in the Middle Mountain forests for the periodic measurement of various forest parameters. These PSPs were measured in 2018/2019. An additional 343 plots in 111 clusters were established to enhance the reliability of the forest inventory and were measured in 2019/2020. This report presents: (1) the Middle Mountain forest statistics based on the measurement of a total of 771 plots (428 PSPs previously established by DFRS and 343 additional plots) between 2018 to 2020, and (2) the area statistics of the Middle Mountain forests based on the National Land Cover Monitoring System (FRTC, 2022).

1.2. The Environment of the Middle Mountain Forests

Middle Mountains also known as Mid hills, extends from 80° 14' 27" to 88° 11' 9" longitudes and 26°46' 46" to 29° 19' 32" latitudes (**Figure 1**). This region lies at north of Churia (Siwalik) region along the southern flanks of the Himalayas with an elevation difference between 110 m to 3300 m (LRMP, 1986). The Main Boundary Thrust (MBT) serves as the border between the Churia and southern Middle Mountains, the uplifted Mahabharat range (LRMP, 1986). The region occupies about 4,302,265 ha (29.08%) of the total land area (14,793,015 ha) of the country and covers parts of 56 of the nation's 77 districts (FRTC, 2022).

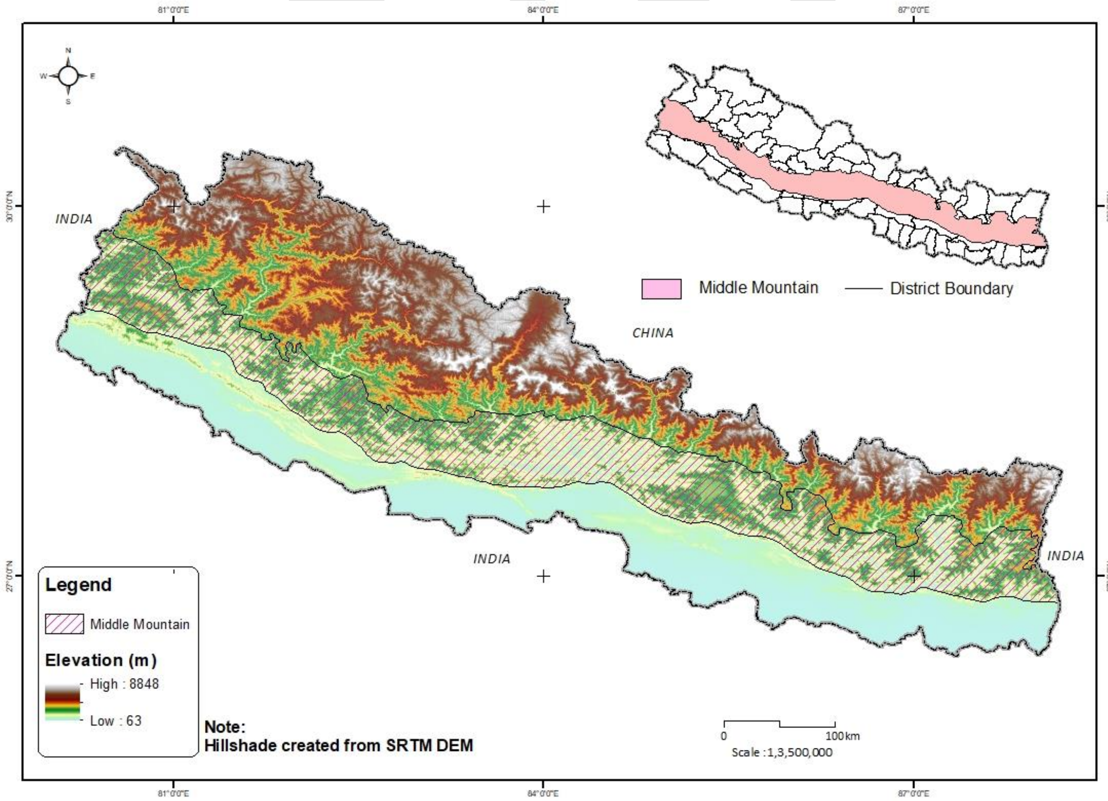

Figure 1: The spatial extent of the Middle Mountain in Nepal

Soils

The valleys of Middle Mountains region, below the steep slopes, have alluvial loamy and sandy soils. On higher slope positions, the loam is mixed with boulders and exposed bedrock (Dijkshoorn and Huting, 2009). The area is partly covered by glacial deposits formed during the last ice age. Such soils may become unstable when wet. Because of the steep slopes and dynamic geological conditions, large-scale landslides are common in the area during the monsoon, especially where the soil has been exposed by roads and agricultural terracing.

Mountain forests are typically rich in soil organic carbon (SOC). Since litter and woody debris, collection has an important role in communities. It is possible that in most densely populated areas the aboveground litter input into soil carbon pool may be reduced. On the other hand, belowground input of fine root turn over can sustain the most important carbon input to the soil pool. Forest degradation or conversion to cropland in Middle Mountains constitutes the greatest threat to carbon pools both above-ground and in the soil. The organic rich, loose surface layer of soil can be easily eroded by rains.

Climate

The climate in Middle Mountains ranges from sub-tropical in river valleys to warm-temperate in valleys to cool-temperate in the high hills. The average annual maximum temperature[1] is about 23.5°C (ranging from 5°C to above 40°C); and the average annual minimum, 12.7°C (ranging from -3°C to 30°C). Annual precipitation[2] varies from east to west with the highest in Western Development Region (1,898 mm), followed by Far-Western (1,410 mm), Mid-Western (1,389 mm), Eastern (1,260 mm) and Central Regions (1,091 mm).

Middle Mountains are the first great barrier to monsoon clouds and high precipitation occurs on the southern slopes of the mountains. The conditions support lush vegetation with plenty of climbers and epiphytes. The warm-temperate monsoon climate occurs in the lower part of Middle Mountains, from approximately, 1,000 to 2,000 m, while the upper part, between 2,000 to 3,000 m, has cool-temperate monsoon climatic conditions (Acharya, 2003).

Drainage

The major river systems in the region are the Babai, West Rapti, Tinau, Bagmati, Kamala, Kankai, and Mechi. These rivers, originating in the Lesser Himalaya and the Mahabharat Range, are called second-grade rivers. They are fed by precipitation as well as ground water recharge, including that from springs (WECS, 2011). These rivers are perennial and are commonly characterized by wide seasonal fluctuation in discharge.

1.3. Forest Resource Assessment (2010-2014)

The recent and most comprehensive nationwide forest resource assessment (FRA) was implemented between 2010 and 2014 under the FRA Nepal Project with technical and financial assistance from the Government of Finland. The FRA Nepal Project (2010-2014) provided comprehensive, up-to-date national- level forest resource information for use in national forest policy development and strategic forestry sector decision-making. It used a well-established inventory design (two phase stratified systematic cluster sampling) and took into account national data needs as assessed in 2010. Four physiographic strata, i.e. the Terai, Churia, Middle Mountains, High Mountains and High Himal, were considered for the assessment. The assessment in the Middle Mountains physiographic region was carried out between 2010 and 2014 (DFRS, 2014).

CHAPTER 2: METHODOLOGY

2.1 Introduction

The forest resource assessment in the Middle Mountain included remeasurement of existing permanent sample plots (PSPs) as well as establishment and measurement of additional PSPs. The measurement of PSPs followed the standard field measurement protocols used in FRA-Nepal Project (DFRS, 2014). National scale remote sensing based forest cover mapping was also implemented.

2.2 Forest Inventory

2.2.1 Sample plot selection

The forest inventory involved remeasurement of the PSPs established by the FRA Nepal Project (2010-2014) and an additional number of plots established using the same methodology. The inventory design adopted was based largely on methods developed by Kleinn (1994) and finalized by the DFRS (Figure 2).

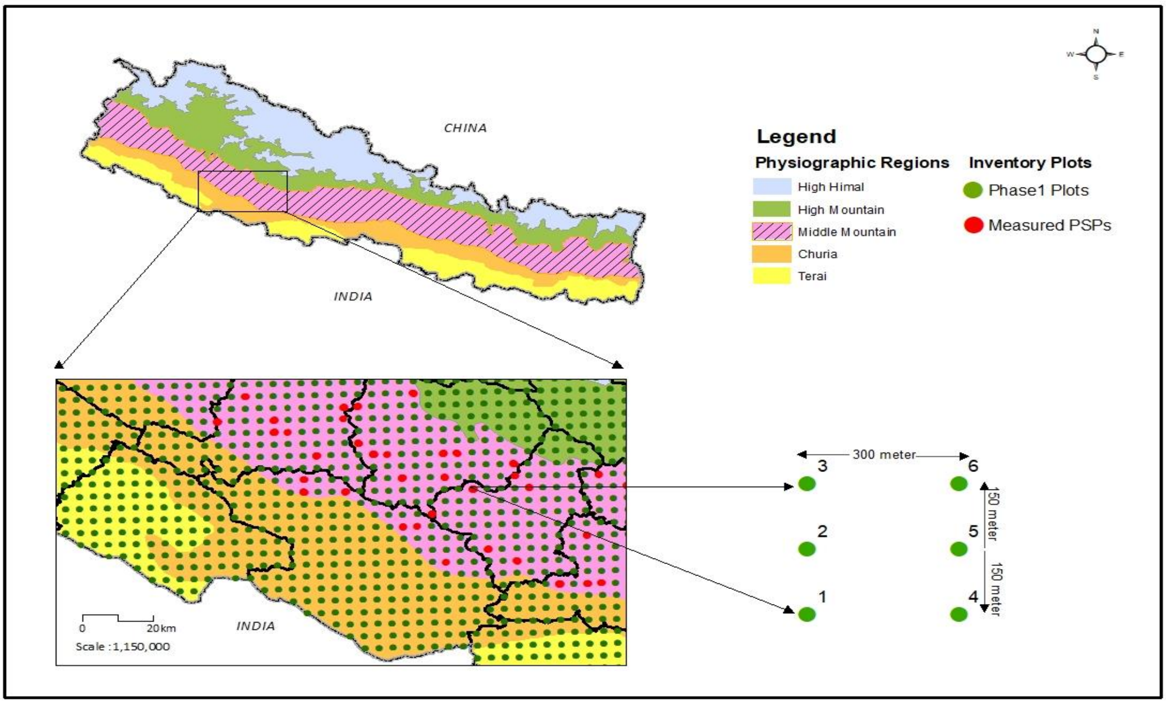

Figure 2: Layout of the clusters and plot within each cluster

The detailed methodology adopted for sample selection is presented in DFRS, 2014. Altogether 771 plots (428 PSPs and 343 additional PSPs from 147 and 111 clusters respectively) were measured for this assessment (Figure 3).

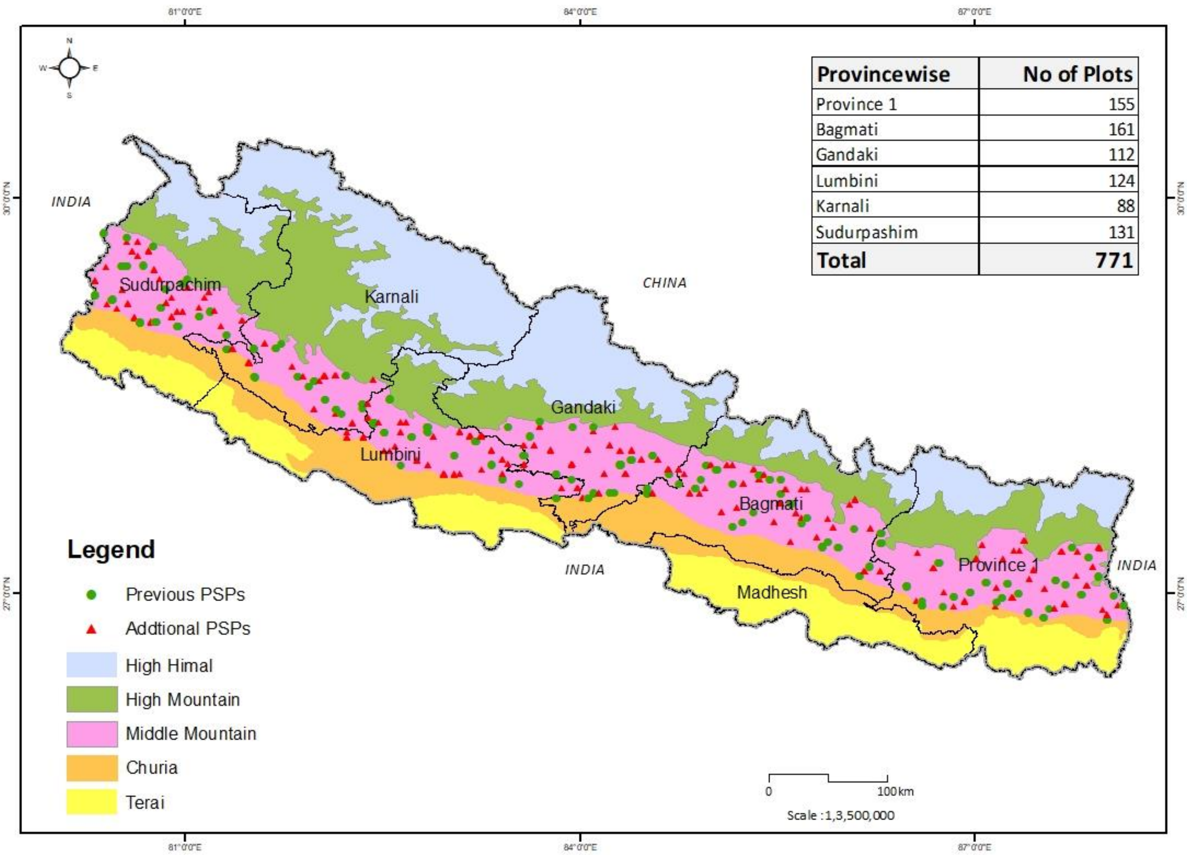

Figure 3: Map of Nepal showing the distribution of PSPs in Middle Mountain

2.2.2 Sample plot design

The concentric circular sample plot (CCSP) design was adopted as used by the FRA Nepal Project (2010-2014). Each sample plot had four concentric circles of different radii (Figure 4), which were used to measure trees with different DBH as follows:

- trees having 30 cm DBH or more enumerated within a 20 m radius plot (area: 1256.6 m^2)
- trees having 20-29.9 cm DBH enumerated within a 15 m radius plot (area:706.9 m^2)
- trees having 10-19.9 cm DBH enumerated within an 8 m radius plot (area:201.0 m^2)
- trees having 5-9.9 cm DBH enumerated within a 4 m radius plot (area: 50.3 m^2)

Other subplots were established to assess forest attributes other than trees, such as seedlings, saplings, shrubs, and herbs. Seedlings, saplings, and shrubs were measured in four circular subplots of 2 m radius, located at 10 m from the plot centre in each cardinal direction. Species-wise, stem counting and mean height estimation was done for tree and shrub species with DBHs less than 5 cm. Besides, diameter of shrub was measured near the root collar. Information on non-woody vascular plants was collected from four 1 m^2 square plots, each located 5 m away from the plot centre in the four cardinal directions. Dead and decaying wood was assessed in a circular plot with a radius of 10 m from the plot centre. Based on field observations, 15 categories of natural and anthropogenic forest disturbances were assessed in terms of their occurrence and intensity (high, medium, low) on the sub-plot with a 20 m radius.

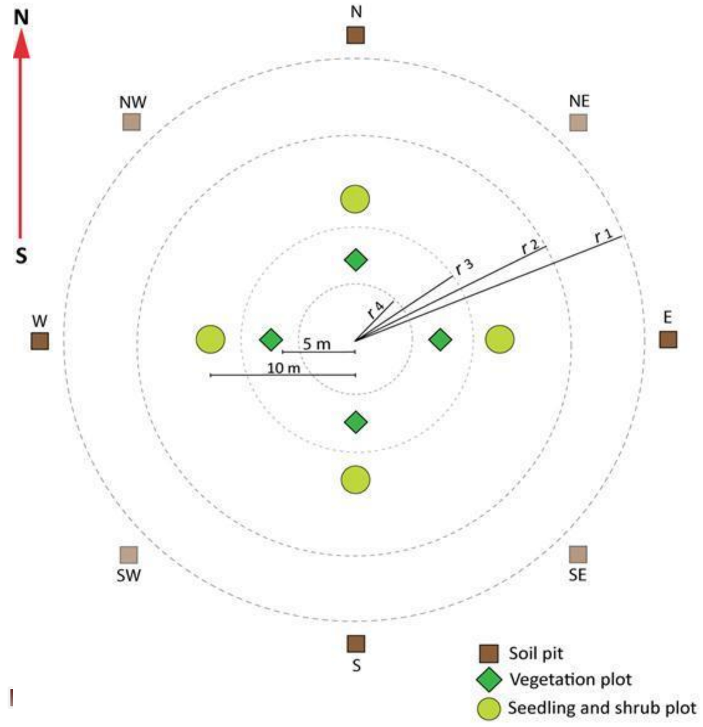

Figure 4: Layout of the concentric circular plot with other sub-plots

2.2.3 Quality assurance of forest inventory data

Use of periodically revised field manual, training to field crews and regular monitoring and feedback were some of the measures applied to maintain the quality of the inventory results. To check the quality of the results, at least 10% of the total PSPs measured were systematically selected (with a random start) and re-measured.

2.2.4 Tree height modelling

The total height of trees is an important predictor of volume and biomass. Still, its measurement for all trees under forest conditions can be time-consuming and impractical. On the other hand, diameter at breast height (DBH) is a frequently used tree characteristic in forest inventories as it is an easily measurable variable (Gering, 1995). The FRA field manual thus suggests to measure tree heights only for the sample trees. Furthermore, for top broken, dead trees and stumps, tree heights are measured at the existing tip. Hence, tree diameter height modelling is required to impute the heights for all those trees for which field measurements were not taken. The missing tree heights were imputed using the different functions (Annex 1) implemented in the R package *Lmfor* (Mehtatalo, 2012).

2.2.5 Volume and biomass estimation

Tree volume estimation:

Equation 1, developed by Sharma and Pukkala (1990), was used to estimate tree volume over bark.

Equation 1: Tree volume

$$\ln(v) = a + b\ \ln(d) + c\ \ln(h)$$

where,

ln = Natural logarithm to the base 2.71828.

V = Volume (dm^3) = exp [a + b×ln(DBH) + c×ln(h)]

d = DBH in cm
h = Total tree height in m
a, b and c are coefficients depending on species
Values were divided by 1000 to convert them into cubic meters.

The regression parameters are presented in Table 1.

Table 1: Species-specific coefficients used for calculating volumes of individual trees

SN	Species	Localname	a	b	c
1	*Acacia catechu*	Khair	-2.3256	1.6476	1.0552
2	*Adina cordifolia*	Haldu/Karma	-2.5626	1.8598	0.8783
3	*Albizia* spp.	Siris	-2.4284	1.7609	0.9662
4	*Alnus nepalensis*	Utis	-2.7761	1.9006	0.9428
5	*Anogeissus latifolia*	Banjhi	-2.2720	1.7499	0.9174
6	*Bombax ceiba*	Simal	-2.3865	1.7414	1.0063
7	*Toona ciliata*	Tooni	-2.1832	1.8679	0.7569
8	*Dalbergia sissoo*	Sissoo	-2.1959	1.6567	0.9899
9	*Syzygium cumini*	Jamun	-2.5693	1.8816	0.8498
10	*Lagerstroemia parviflora*	Bot dhaiyero	-2.3411	1.7246	0.9702
11	*Magnolia champaca*	Chanp	-2.0152	1.8555	0.7630
12	*Pinus roxburghii*	Khotesalla	-2.9770	1.9235	1.0019
13	*Pinus wallichiana*	Gobresalla	-2.8195	1.7250	1.1623
14	*Quercus* spp.	Khasru	-2.3600	1.9680	0.7469
15	*Schima wallichii*	Chilaune	-2.7385	1.8155	1.0072
16	*Shorea robusta*	Sal	-2.4554	1.9026	0.8352
17	*Terminalia alata*	Asna	-2.4616	1.8497	0.8800
18	Miscellaneous in Terai		-2.3993	1.7836	0.9546
19	Miscellaneous in Hills		-2.3204	1.8507	0.8223

Source: Sharma and Pukkala (1990)

The total volume of broken trees was estimated using a taper curve equation developed by Heinonen *et al.* (1996), mentioned in Annex 2.

Tree stem biomass estimation:

The tree-stem biomass was calculated using Equation 2 (MFSC, 1988) and the species-specific wood-density values (Sharma and Pukkala, 1990) (Table 2). The air-dried biomass values obtained using these equations were converted into oven-dried biomass values by applying a conversion factor of 0.91 (Chaturvedi, 1982; Kharal and Fujiwara, 2012) and a carbon-ratio factor of 0.47 (IPCC, 2006).

Equation 2: Tree stem biomass

$$\text{Stem biomass} = \text{Vol} \times \text{density}$$

where,

Vol = Stem volume in cubic meters
Density = Air-dried wood density (kg/m^3)

Table 2: Stem wood-density of Middle Mountain trees

Species	Localname	Air-drieddensity(kg/m^3)
Acacia catechu	Khair	960
Adina cordifolia	Haldu/Karma	670
Albizia spp.	Siris	673
Alnus nepalensis	Utis	390
Anogeissus latifolia	Banjhi	880
Bombax ceiba	Simal	368
Castanopsis spp.	Katus	740
Toona ciliata	Tooni	480
Dalbergia sissoo	Sissoo	780
Syzygium cumini	Jamun	770
Lagerstroemia parviflora	Bot dhaiyero	850
Litsea spp.	Kutmiro	610
Magnolia champaca	Chanp	497
Myrica esculanta	Kaphal	750
Pinus roxburghii	Khotesalla	650
Pinus wallichiana	Gobresalla	400
Quercus spp.	Khasru	860
Rhododendron spp.	Gurans	640
Schima wallichii	Chilaune	689
Shorea robusta	Sal	880
Terminalia alata	Asna	950
Miscellaneous in Terai		674
Miscellaneous in Hills		674

Source: Sharma and Pukkala (1990)

Tree branch and foliage biomass estimation:

The separate branch-to-stem and foliage-to-stem biomass ratios prescribed by MFSC (1988) were used to estimate branch and foliage biomass from stem biomass (Table 3).

Table 3: Branch-to-stem and foliage-to-stem biomass ratios of trees

Species	Localname	Branch-to-stem			Foliage-to-stem		
		Small	Medium	Big	Small	Medium	Big
Alnus nepalensis	Utis	0.803	1.226	1.510	0.169	0.089	0.060
Castanopsis spp.	Katus	0.398	0.915	1.496	0.053	0.048	0.042
Dalbergia sissoo	Sissoo	0.684	0.684	0.684	0.010	0.010	0.010
*Lyonia*spp.	Angeri	0.879	0.709	0.670	0.506	0.714	0.850
Myrica esculenta	Kaphal	0.524	0.590	0.605	0.170	0.160	0.155
Pinus roxburghii	Khote salla	0.189	0.256	0.300	0.101	0.046	0.033
Pinus wallichiana	Gobresalla	0.683	0.488	0.410	0.403	0.238	0.180
Quercus spp.	Khashru	0.747	0.960	1.060	0.229	0.215	0.202
Rhododendron spp.	Gurans	0.544	0.910	1.135	0.277	0.225	0.212
Rhus spp.	Bhalayo	0.601	0.630	0.640	0.143	0.083	0.080
Schima wallichii	Chilaune	0.520	0.186	0.168	0.064	0.035	0.033

Shorea robusta	Sal	0.055	0.341	0.357	0.062	0.067	0.067
Other species	-	0.400	0.400	0.400	0.070	0.050	0.040

Source: MFSC (1988)

The total biomass of individual trees was estimated using Equation 3: Total biomass of an individual tree.

Equation 3: Total biomass of an individual tree

Total biomass = Stem biomass + branch biomass + foliage biomass

Tree stump and coarse root biomass estimation:

It was calculated using Equation 4: Stump volume estimation (Altrell *et al.,* n.d.).

Equation 4: Stump volume estimation

$$Vol_{stump} = (D_{sh}^2)/4 \times H_{stump} \times \pi \times F_{stump}$$

where,

D_{sh} = Stump diameter

H_{stump} = Stump height

F_{stump} = Stump form factor 1.5 (stump form-factors range from 1.3 to 2.0)

2.2.6 Reliability of estimates

The stem volume per hectare was considered as the main variable for assessing the reliability of results. The reliability was estimated in terms of standard error of the mean stem volume. The desired accuracy was 10 % at 95% confidence level. The variance of mean volume estimate in forest was estimated by using the variance estimator of a ratio estimator (Equation 5) proposed by Cochran (1977).

Equation 5: Variance of mean volume estimate

$$v(\bar{x}_p^{(F)}) = \frac{1}{(\sum^{n_p} m_i)^2} \frac{n_p}{n_p - 1} \sum^{n_p} \left(x_i - \bar{x}_p^{(F)} \cdot m_{p,i}\right)^2$$

Where,

n_p =number of clusters with at least one forest plot

$m_{p,i}$ = number of forest plots in cluster i

x_i = sum of plot level volumes in cluster i, m^3 /ha

$\bar{x}_n^{(F)}$ = mean volume in forest

p refers to physiographic region.

2.3 Forest Cover Mapping

Forest-cover maps for Middle Mountain were derived as a subset of the national land cover maps prepared by the National Land Cover Monitoring System (NLCMS) of Nepal (FRTC, 2022). In brief, the mapping method included collecting training samples for different land cover, preparation of annual

Landsat composites, image indices and other covariates, predicting land cover maps using decision trees, and finally, validation and accuracy assessment (Figure 5).

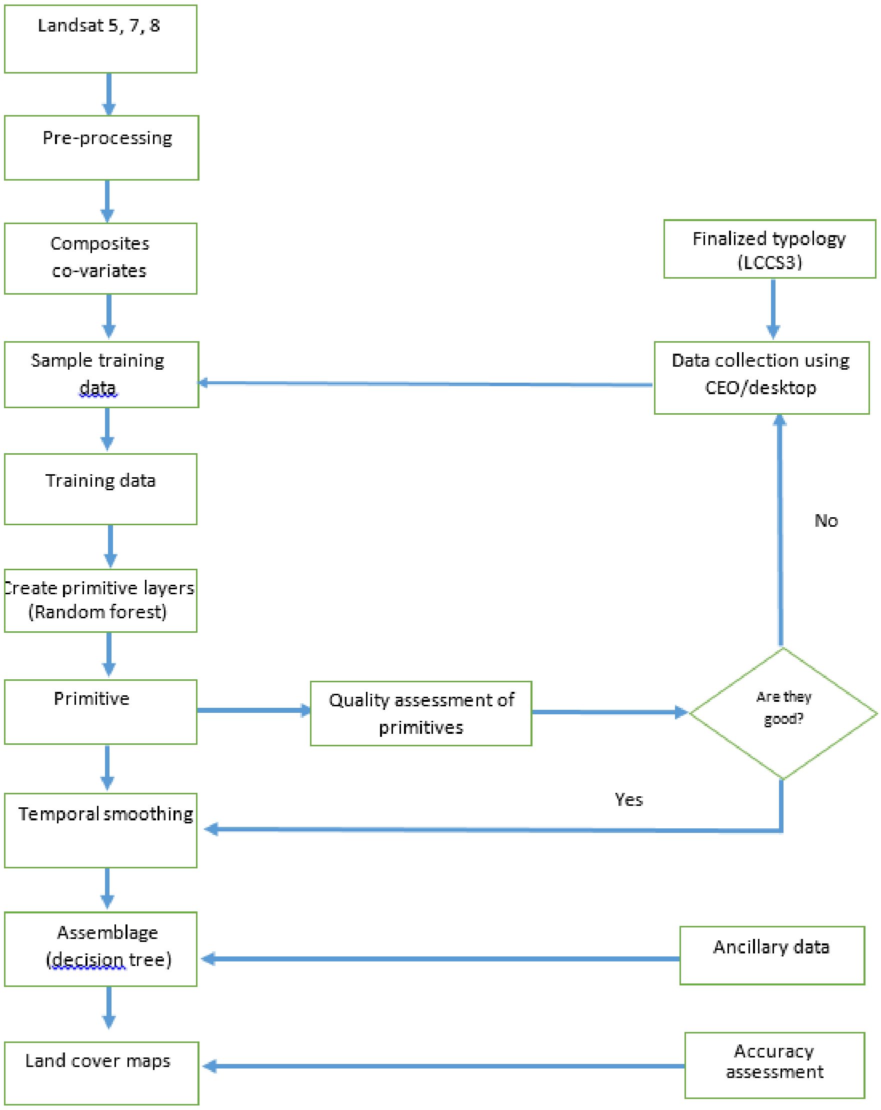

Figure 5: A flowchart showing the overall method of the NLCMS

2.4 Forest Soil Assessment

Soil samples were collected from the top 30cm soil layer in each plot and analyzed in the accredited soil laboratory at the FRTC to estimate soil organic carbon (SOC) stock in the forests.

2.4.1 Collection of samples of litter, woody debris and soil from the field

Soil Sampling Locations

Soil sampling was conducted along the periphery of the CCSP established for forest inventory. The soil pits were dug 21 meters away from the CCSP-centre towards the four sub-cardinal directions, i.e. alternative soil pits, as shown in Figure 6. A composite sample of litter, woody debris, and soil was collected separately from each CCSP, except for the plots in the croplands, steep slopes (>100%), rocky areas, riverbanks, roads and water bodies. In the case of the CCSPs falling under two or more forest stands, the litter, debris, and soil samples were collected, establishing at least one soil pit within each stand.

Litter and Woody Debris Sampling

After locating the soil pits on the ground, litter and debris fractions were collected from 1 m^2 circular plots on the surface of each soil pit before taking soil samples. Litter and woody debris from all the four sub-plots were collected separately to make their composite samples. In the case of the pits without any litter or woody debris, the '0' value was recorded for the pit to estimate a correct average litter and debris mass per unit area.

The total composite fresh mass of both the litter and debris were weighed in the field to an accuracy of 1.0 g. If the total volumes of litter and debris collected from the 4 m^2area (four 1 m^2 plots) were very large, one-quarter or one-half of the total samples were taken to determine their dry mass in the laboratory.

Soil Sampling

To collect undisturbed soil samples, soil pits of appropriate size were dug within a 2 m × 2 m area. The undisturbed soil samples were collected using a Cylindrical Corer having 40 mm diameter (37 mm diameter at its cutting-edge) and 100 mm length; the volume of each soil sub-sample being 107.5 cm^3.

The FRA field manual specified collecting the composite soil samples from three layers: 0-10 cm, 10-20 cm, and 20-30 cm depths from each cardinal direction (Figure 6). However, to avoid the disturbed soil during the FRA 2010-2014, soil samples were collected from the four sub-cardinal directions in second measurement. The fresh mass of the composite sample was determined with the accuracy of 1 gram. The soil samples from three layers were collected separately in the polythene bags from the field and brought to the laboratory; the samples were kept separately to assess the within-site variability of SOC.

The relative volume of stones in the soil was estimated by observing the soil pit walls and using the FAO Guidelines (2006).

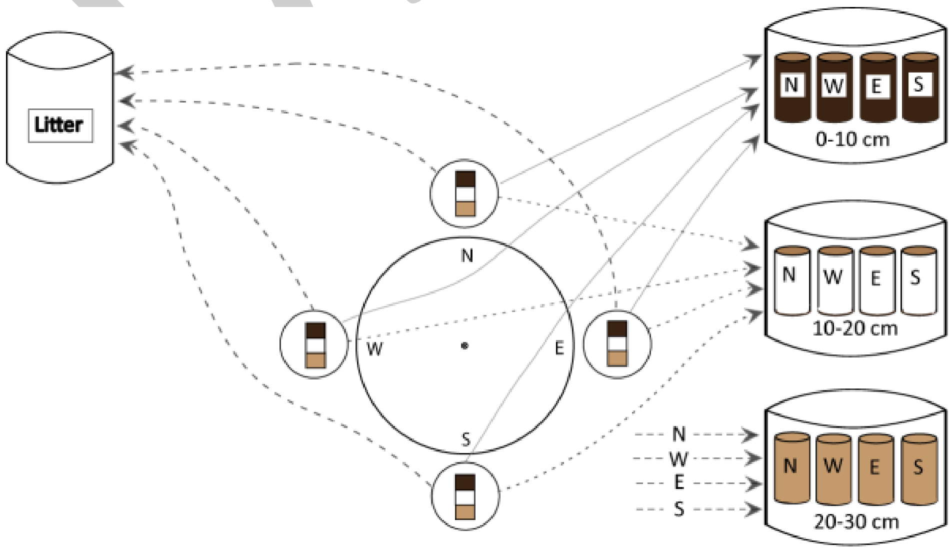

Figure 6: Collection of composite samples of litter, debris and soil from a plot

2.4.2 Analyses of samples in the laboratory

Determination of Physical Parameters

The composite samples of soil, litter and woody debris were analysed in the soil laboratory. SOC was calculated from dry soil bulk density (g/cm^3) and the proportion of soil organic carbon. Dry bulk density of the fine soil fraction (< 2mm) was determined from the volumetric composite samples to calculate the soil organic carbon stock in each 10 cm deep layer down to 30 cm below the soil surface. Before analysis, pebbles, gravels, and stones >2 mm were removed from the soil samples. All the particles less than 20 mm in diameter found in the volumetrically cored samples were eliminated to calculate the bulk density of the fine fraction.

The coarse fraction was separated using a 2 mm sieve, and its volume was measured using the water displacement method to calculate the bulk density of the fine fraction. The fine fraction that passed through the sieve was homogenised and analysed for OC%. The overall 0-30 cm soil layer SOC stock (t/ha) was derived by multiplying the OC% with the fine fraction bulk density of the respective sample, and it was further corrected with the proportion of large stones estimated for the 30 cm deep soil layer. The correction was applied using average values of SOC (t/ha) and the average stone volume of the strata reported in the results. Results of each 10 cm layer kept separate in analyses were summed to obtain SOC stored in the fine fraction of 0-30 cm soil layer.

Litter, Woody Debris, and Soil Carbon Analysis

The preparation of the samples and the SOC analysis followed the procedures detailed in the Laboratory SOP (FRA Nepal, 2011), as summarised below. Litter and woody debris were not analysed for OC%, but a constant carbon content of 50% (Pribyl, 2010) was applied with an estimate of dry mass/m^2. The oven-dry weight of the litter and woody debris was estimated by multiplying the ratio of oven-dry weight to the fresh weight of the litter and woody debris subsamples.

Before oven drying to achieve a constant weight and moisture content, the soil samples brought from the field to the FRTC laboratory were first air-dried until they were fully stabilised. Walkley-Black Wet Combustion Method (Walkley and Black, 1934), together with titration, was applied to analyse the proportion of OC% in the soil. As this method can recover only about 77 % of SOC, a correction factor of 1.33 was applied to determine the actual amount of SOC. An excel application was produced to collect all laboratory calculations and help organise and speed up the laboratory calculations. The application also calculated the carbon stocks of litter, woody debris, and soil fine fraction.

2.5. Limitations of the results

2.5.1 Forest inventory

The methodology was designed to collect data on tree volume and biomass in the entire Middle Mountain region with 95% confidence of being within plus or minus 10% of the actual value. The application of results for any sub-populations, such as a district or province, would be limited. Similarly, the confidence level of results for parameters other than tree volume and biomass could be lower.

Sampling errors can only be assessed if estimated values are distributed normally and there is no bias. Besides, other potential sources of inaccuracy include errors in identifying species, taking field measurements, entering field results in the database, and deriving and calculating mathematical formulae. Errors in area estimation influence the total values of growing stock, biomass and carbon while converting from average values.

The inventory data analysis relied on the biomass equations developed by Sharma and Pukkala (1990), developed using the data measured in the 1960s. In addition, there were insufficient species-specific wood densities available for the tree species. Stem to branch and foliage biomass ratios were available only for a few species (Table 3). The biomass values obtained from the biomass tables provide only air-dry biomass values. These limitations might influence the precision of estimating above and belowground wood biomass and carbon content in the Middle Mountain Forests.

Result of biodiversity analysis provides indicative figures of abundance of species in sample plots level. Number of family genera and species for shrubs and NTFPS is taken from sample plots only, unlike FRA 2010-2014 where those were considered from social survey as well.

2.5.2 Forest cover mapping

Potential sources of uncertainty in forest cover maps could be introduced due to limited coverage of high-resolution satellite images for earlier years in contrast to more frequent and quality reference images available for recent years. As the Landsat allows coarser scale mapping (e.g. 30 m spatial resolution equivalent to 0.09 ha), many small scale land cover and changes are not represented in the maps. Therefore, the area estimates are expected to vary with the previous estimates derived in FRA 2010-2014. Due to the spatial heterogeneity of the forest stands and the fuzziness of their boundary limits, errors might have been introduced in the classification and delineation of such forest stands.

2.5.3 Soil analysis

Soil sampling was done only in the sample plots designed for the forest inventory, specifically the tree volume and biomass estimation. Therefore, it might not have represented all the micro-site variabilities within the Middle Mountain region. As a result, the confidence intervals of the estimates were appeared to be wide. Bringing samples from field to FRTC soil laboratory can often take long duration, which may lower the quality of sample and may affect the results.

CHAPTER 3: RESULTS

3.1. Area Statistics of the Middle Mountain Forest

Forest and Other Wooded Land (OWL) occupy 60.70% (26,11.307 ha) and 3.66 % (1,57,408 ha) of the total area of the Middle Mountain Region, respectively. Thus, Forest and OWL together cover 64.36 % of the total land cover in the Middle Mountain (Table 4).

Table 4: Land cover in the Middle Mountain, 2019

Land cover class	Area	
	Ha	%
Forest	2,611,307	60.70
Other Wooded Land (OWL)	157,408	3.66
Other land	1,533,550	35.64
Total	**4,302,265**	

The land cover map of the Middle Mountain physiographic region is presented in Figure 7.

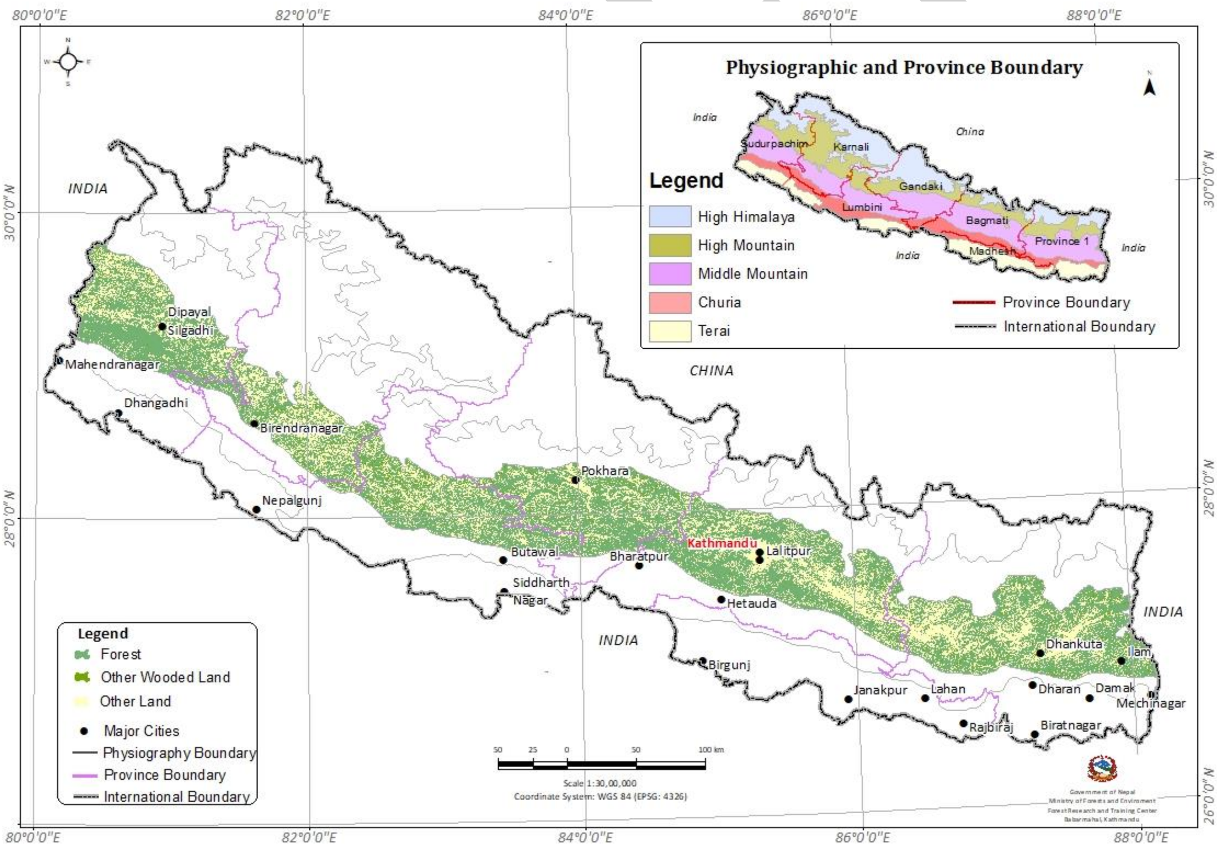

Figure 7: Land cover map of the Middle Mountain region, 2019

3.2. Middle Mountain Forest Inventory Results

The main results presented here include the number of stems, basal area, volume, biomass, and carbon stock. Furthermore, results on forest disturbances, shrubs and small trees (seedling/sapling), biodiversity, and NTFPs are also included. The species that contribute one percent or above to the total growing stock of the Middle Mountain forests are included in the result tables and graphs.

3.2.1 Number of stems

The Middle Mountain forests of Nepal contain a total of 2450.79 million live stems with DBH>=5cm, the average being 938.53 per hectare. There are 80.04 million standing dead stems (30.65 per hectare), of which more than 90 percent are usable. Co-dominant stems constitute the highest proportion of stems in the Middle Mountain forests, followed by dominant ones. About 17.40 stems per hectare were removed annually in the last five years by different natural and anthropogenic causes (Table 5).

Table 5: Number of stems per ha by crown class

Status of stem	Crown class	No. of stems/ha
Live stems	Dominant	281.33
	Co-dominant	284.85
	Intermediate	213.35
	Suppressed	58.48
	Understory	12.68
	Top-broken	87.84
Sub-total **(live stems)**		**938.53**
Standing dead stems	Dead usable	28.77
	Dead unusable	1.88
Sub-total **(standing dead stems)**		**30.65**
Stem removal (last five years)		**86.98**

Shorea robusta is the most abundant species in the Middle Mountain forests (184.15/ha), followed by *Schima wallichii* (78.87/ha). The numbers of saplings (5-10 cm), poles (10-20 cm), small saw-timber (20-50 cm) and large saw-timber (50 cm or above) are 457.38, 327.38, 56.91 and 11.88, respectively. The average weighted DBH and height of stems are 33.13 cm and 14.16 m, respectively, with *Quercus* species having the largest Average weighted DBH (48.33 cm) and *Pinus roxburghii* have highest Average weighted height (20.79 m) (Table 6).

Table 6: Number of stems per ha by species and DBH class

Species Name	5-10	10-20	20-30	30-50	>50	Total	Weighted (DBH)	Weighted (HT)
Shorea robusta	81.54	69.99	22.68	8.62	1.32	184.15	27.44	14.90
Rhododendron species	35.35	30.25	6.59	3.57	1.02	76.79	31.03	9.55
Quercus species	24.00	25.03	7.72	3.27	1.54	61.56	48.33	13.54
Schima wallichii	31.48	31.16	10.92	4.51	0.81	78.87	30.22	13.50
Castanopsis species	17.03	17.87	6.37	2.84	0.58	44.68	31.76	13.05
Lyonia species	28.90	18.26	3.34	1.15	0.26	51.90	23.92	8.59
Terminalia alata	6.71	2.77	1.17	0.93	0.51	12.09	43.34	19.59
Adina cordifolia	0.52	0.77	0.35	0.25	0.12	2.01	44.80	17.63

Mallotus philippensis	8.52	3.35	0.50	0.04	0.00	12.41	15.03	8.57
Lagerstroemia parviflora	6.19	4.19	1.17	0.51	0.04	12.11	24.74	12.78
Acacia catechu	1.55	1.42	0.55	0.04	0.01	3.57	21.48	13.13
Pinus roxburghii	11.87	14.06	10.04	7.21	2.11	45.29	38.28	20.79
Pinus wallichiana	1.29	2.13	2.29	1.35	0.18	7.24	32.85	18.91
Others	202.45	106.12	23.17	10.74	3.40	345.88	32.70	13.33
Total	**457.38**	**327.38**	**96.86**	**45.03**	**11.88**	**938.54**	**33.13**	**14.16**

The majority of stems (64.17%) in the Middle Mountain forests is in the quality class III, termed here as cull trees, and followed by high-quality sound trees (quality class I) with 21.26%. Only 14.57% of stems are found from quality class II, termed here as sound trees (Figure 8).

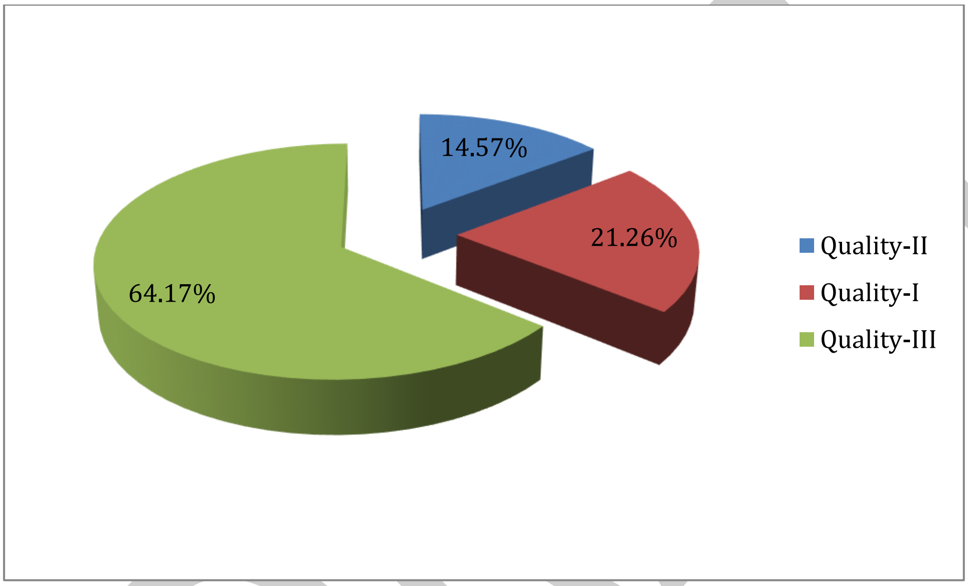

Figure 8: Number of stems by quality classes expressed as percentage

Shorea robusta, the most abundant and one of the most valuable timber-yielding species in the Middle Mountain, has the largest number of high-quality stems, with about 38.91%, 27.48% and 12.44% of its stems in quality-I, quality-II and quality-III, respectively and followed by *Pinus roxburghii* (19.52%), *Schima wallichii* (25.83) and *Rhododendron species*(11.88%) of its stems in quality-I,quality-II and quality-III , respectively (Table 7).

Table 7: Number of stems per ha by species and quality class

S.N.	Species Name	Quality Class 1	Quality Class 2	Quality Class 3	Total
1	*Shorea robusta*	53.20	54.83	76.12	184.15
2	*Rhododendron species*	0.37	4.83	71.58	76.79
3	*Quercus species*	2.95	12.75	45.86	61.56
4	*Schima wallichii*	11.76	25.83	41.28	78.87
5	*Castanopsis species*	7.03	11.97	25.68	44.68
6	*Lyonia species*	0.04	2.01	49.85	51.90
7	*Terminalia alata*	2.62	1.91	7.56	12.09

8	*Adina cordifolia*	0.35	0.61	1.05	2.01
9	*Mallotus philippensis*	0.02	1.96	10.43	12.41
10	*Lagerstroemia parviflora*	0.63	3.89	7.58	12.11
11	*Acacia catechu*	0.45	1.50	1.61	3.57
12	*Pinus roxburghii*	26.69	10.90	7.70	45.29
13	*Pinus wallichiana*	5.07	1.57	0.60	7.24
14	Others	25.54	64.95	255.39	345.88
	Total	**136.72**	**199.53**	**602.30**	**938.54**

3.2.2 Number of seedlings and saplings

The number of seedlings (DBH < 5 cm, height < 1.3 m) and saplings (DBH < 5 cm, height > 1.3 m) in the Middle Mountain forests are 4,955 and 1,318 per hectare, respectively. Like the larger stems, *Shorea robusta* has the largest number of seedlings and saplings, followed by *Castanopsis* species (Table 8).

Table 8: Number of seedlings and saplings per ha by species

Sceintific Name	Seedlings (No./ha)	Saplings (No.ha)	Total (No./ha)
Shorea robusta	1839.26	257.00	2096.26
Rhododendron species	120.24	41.29	161.53
Quercus species	109.41	29.42	138.82
Schima wallichii	183.89	75.60	259.50
Castanopsis species	264.40	98.31	362.71
Lyonia species	145.27	61.67	206.94
Terminalia alata	91.34	9.55	100.89
Adina cordifolia	2.32	2.06	4.39
Mallotus philippensis	153.79	96.25	250.03
Lagerstroemia parviflora	30.45	28.90	59.35
Acacia catechu	16.00	8.00	24.00
Pinus roxburghii	190.43	18.84	209.27
Pinus wallichiana	1.03	3.61	4.64
Others	1807.27	587.28	2394.55
Total	4955.10	1317.78	6272.88

Out of all forest types, *Shorea robusta* forest holds the greatest number of regenerations. The total number of seedlings and saplings has increased with an increase in canopy cover class. Similarly, in terms of development stage of a forest, the highest number of regenerations is found in large saw timber stand. Also, out of all forest management regimes, Buffer Zone Community Forest have the highest number of regenerations (Table 9).

Table 9: Number of seedlings and saplings by different forest attributes

Forest Type	No of plots	Seedlings/ha	Saplings/ha	Total (No/ha)
Pr (*Pinus roxburghii*)	98	4531.04	1047.50	5578.54
S (*Shorea robusta*)	104	9437.07	1560.94	10998.01
Q (*Quercus* species)	28	2785.21	859.72	3644.93
LMH (Lower Mixed Hardwood)	309	3634.42	1295.39	4929.81
UMH (Upper Mixed Hardwood)	85	2892.88	1357.50	4250.37

TMH (Terai Mixed Hardwood)	132	6617.89	1380.55	7998.44
KS/SK (Khair Sissoo)	4	7609.60	2387.32	9996.92
Pw (*Pinus wallichiana*)	9	4398.87	1967.33	6366.20
A (*Abies* species)	1	596.83	795.77	1392.61
Other	1	0.00	0.00	0.00
Weighted average	**771**	**4955.10**	**1317.78**	**6272.88**
Crown Cover		**Seedlings/ha**	**Saplings/ha**	**Total (No/ha)**
Poorly stocked forest (0-39%)	120	3802.03	1032.85	4834.88
Moderately stocked forest (40–69.9% canopy closure)	372	4539.34	1263.72	5803.06
Well-stocked forest (≥70% canopy closure)	279	6005.39	1512.40	7517.79
Weighted average	**771**	**4955.10**	**1317.78**	**6272.88**
Development Status		**Seedlings/ha**	**Saplings/ha**	**Total (No/ha)**
Seedling and sapling stand (<12.5 cm DBH)	22	3807.06	1220.79	5027.85
Pole timber stand (12.5–25.0 cm DBH)	356	4794.77	1257.93	6052.69
Small saw timber stand (25.0–50.0 cm DBH)	277	4923.80	1419.18	6342.98
Large saw timber stand (>50.0 cm DBH)	116	5739.64	1277.70	7017.34
Weighted average	**771**	**4955.10**	**1317.78**	**6272.88**
Management Regimes		**Seedlings/ha**	**Saplings/ha**	**Total (No/ha)**
Private Forest	120	3990.48	1545.13	5535.61
Government Managed Forests	182	3364.55	1070.14	4434.70
Protected Area	1	198.94	596.83	795.77
Buffer zone Community Forest	3	9549.30	2851.53	12400.82
Conservation Area	6	928.40	729.46	1657.86
Community Forests	444	6009.23	1367.07	7376.30
Leasehold Forest	2	1094.19	895.25	1989.44
Public Land Forest	4	1840.23	1541.81	3382.04
Other	9	1481.03	707.36	2188.38
Weighted average	**771**	**4955.10**	**1317.78**	**6272.88**

3.2.3 Basal area

The total basal area of live trees in the Middle Mountain forests is more than 20.78 m^2/ha, of which more than 50% (11.68 m^2/ha) comprised of the dominant trees. The total basal area of both standing dead trees and trees that had been removed (assessed by the presence of stumps) were minimal (Table 10).

Table 10: Basal area per ha by crown class

Status of stem	Crown class	Basal area m^2/ha	Percent
Live trees	Dominant	11.68	56.21
	Co-dominant	5.37	25.84
	Intermediate	2.18	10.49
	Suppressed	0.38	1.83
	Understory	0.07	0.34
	Top Cut	1.09	5.25
Subtotal		**20.78**	
Standing Dead Trees	Dead Usable*	0.48	
	Dead Unusable	0.05	
Subtotal		**0.53**	
Stump		0.79	
Removed	Felled	0.77	
	Missing	0.43	
Extraction within 7 years**		**1.20**	
Grand total		**23.30**	

*Tree stems that can be used for firewood

** *A seven-year estimate*

Basal area per hectare is the highest (5.35 m^2) for diameter class 10-20 cm. The second highest basal area (4.96 m^2/ha) is in the diameter class 30-50 cm, whereas the lowest basal area (1.94 m^2/ha) is for saplings (5-10 cm). *Shorea robusta* constitutes the largest proportion of basal area in the Middle Mountain forests (18.72%), followed by *Pinus roxburghii* (10.50%) and *Quercus* spp (9.63%). In terms of stem size, *Quercus* spp holds the highest basal area (0.73 m^2/ha), followed by *Pinus roxburghii* (0.57 m^2/ha) in the largest stem class (DBH > 50 cm) (Table 11).

Table 11: Basal area per ha by species and DBH class

		Diameter Class					
S.N.	Species Name	5-10	10-20	20-30	30-50	>50	Total
1	*Shorea robusta*	0.35	1.18	1.06	0.92	0.38	**3.89**
2	*Rhododendron* species	0.15	0.48	0.31	0.39	0.31	**1.64**
3	*Quercus* species	0.12	0.42	0.36	0.37	0.73	**2.00**
4	*Schima wallichii*	0.13	0.54	0.51	0.49	0.26	**1.92**
5	*Castanopsis* species	0.07	0.29	0.30	0.31	0.18	**1.16**
6	*Lyonia species*	0.12	0.28	0.15	0.12	0.07	**0.75**
7	*Terminalia alata*	0.03	0.04	0.06	0.12	0.16	**0.40**
8	*Adina cordifolia*	0.00	0.01	0.02	0.03	0.04	**0.10**
9	*Mallotus philippensis*	0.03	0.05	0.02	0.00	0.00	**0.10**

10	*Lagerstroemia parviflora*	0.02	0.07	0.06	0.06	0.01	**0.22**
11	*Acacia catechu*	0.01	0.02	0.02	0.00	0.00	**0.06**
12	*Pinus roxburghii*	0.05	0.24	0.49	0.83	0.57	**2.18**
13	*Pinus wallichiana*	0.01	0.04	0.12	0.14	0.04	**0.35**
	Others	0.84	1.68	1.08	1.18	1.21	**6.00**
	Total	**1.94**	**5.35**	**4.55**	**4.96**	**3.97**	**20.78**

Considering basal area in different quality classes, it is the highest (8.51 m^2 per ha) for quality class III followed by quality class I (7.33 m^2 per ha) and quality class II (4.94 m^2 per ha). Among all species, basal area is the highest at all quality classes in *Shorea robusta* (Table 12).

Table 12: Basal areas by species and Quality class

SN	Species Name	Quality class I	Quality class II	Quality class III	Total
1	*Shorea robusta*	2.00	1.15	0.75	3.89
2	*Rhododendron* species	0.03	0.19	1.42	1.64
3	*Quercus* species	0.51	0.57	0.91	2.00
4	*Schima wallichii*	0.55	0.62	0.76	1.92
5	*Castanopsis* species	0.21	0.36	0.58	1.16
6	*Lyonia* species	0.00	0.04	0.71	0.75
7	*Terminalia alata*	0.26	0.07	0.08	0.40
8	*Adina cordifolia*	0.06	0.02	0.02	0.10
9	*Mallotus philippensis*	0.00	0.02	0.08	0.10
10	*Lagerstroemia parviflora*	0.04	0.08	0.10	0.22
11	*Acacia catechu*	0.02	0.03	0.02	0.06
12	*Pinus roxburghii*	1.88	0.22	0.07	2.18
13	*Pinus wallichiana*	0.32	0.03	0.00	0.35
14	Others	1.45	1.54	3.01	6.00
	Total	**7.33**	**4.94**	**8.51**	**20.78**

3.2.4 Stem volume

The total volume of live stems (DBH >= 5 cm) in the Middle Mountain forests is 374.59 million m^3 (143.45 m^3/ha). Dominant stems constitute the highest proportion of stem volume (64.75%), followed by co-dominant ones (22.77%). The total volume of standing dead stems is 7.89 million m^3 (3.02 m^3/ha), of which more than 92.38 % is usable. A total of 20.29 million m^3 (7.77 m^3/ha) of stem volume is removed in the last seven years (Table 12Table 12).

Table 13: Stem volume per ha by crown class

Status of stem	Crown class	Tree stem volume (m3/ha)	
Standing Live Trees	Dominant	92.88	
	Co-dominant	32.66	
	Intermediate	11.00	
	Suppressed	1.70	
	Understory	0.30	

	Top Cut	4.91	
Sub total		**143.45**	
Standing Dead Trees	Dead Usable*	2.79	
	Dead Unusable	0.23	
Sub total		**3.02**	
REMOVED**		7.77	

Tree stems that can be used at least for firewood
** A seven year estimate

Based on forest types, *Pinus wallichiana* forests had the highest stem volume (229.80 m^3/ha), followed by Upper Mixed Hardwood forests (205.03 m^3/ha). Khair-Sissoo forest had the least stem volume (73.69m^3/ha) (Table 14).

Table 14: Stem volume based on forest type

Forest Type	**No of Plots**	**Stem volume (m^3/ha)**
Pr (*Pinus roxburghii*)	98	144.24
S (*Shorea robusta*)	104	180.91
Q (*Quercus* species)	28	182.26
LMH (Lower Mixed Hardwood)	310	123.72
UMH (Upper Mixed Hardwood)	85	205.03
TMH (Terai Mixed Hardwood)	131	109.03
KS/SK (Khair Sissoo)	4	73.69
Pw (*Pinus wallichiana*)	9	229.80
A (*Abies* species)	1	81.07
Other	1	2.90
Total	**771**	**143.45**

In terms of DBH classes, the stem volume per hectare was 7.14 m^3/ha for saplings (5-10 cm), 28.84 m^3/ha for pole timber (10-20 cm), 71.27 m^3/ha for small saw-timber (20-50 cm), and 36.20 m^3/ha for mature trees (≥50 cm). *Shorea robusta* had the highest stem volume, approximately 20 % of the total, followed by *Pinus roxburghii* with approximately 16 %(Table 15).

Shorea robusta constitutes largest stem volume per ha (29.19 m^3/ha) in the Middle Mountain forests, followed by *Pinus roxburghii* (22.25 m^3/ha). In terms of stem size, the growing stock shows an increasing trend with an increase in DBH class up to diameter class 30-50 cm (Table 15).

Table 15: Stem volume per ha by species and DBH class

Species Name	5-10	10-20	20-30	30-50	>50	Total
Shorea robusta	1.36	7.69	8.41	8.08	3.66	29.19
Rhododendron species	0.51	2.06	1.54	2.08	1.70	7.91
Quercus species	0.40	2.20	2.42	2.90	6.71	14.63
Schimawallichii	0.46	2.79	3.18	3.31	1.95	11.70
Castanopsis species	0.32	1.62	1.90	2.09	1.25	7.18
Lyonia species	0.43	1.25	0.75	0.65	0.39	3.46
Terminalia alata	0.08	0.22	0.47	1.06	1.52	3.35
Adina cordifolia	0.00	0.07	0.11	0.24	0.33	0.75
Mallotus philippensis	0.11	0.24	0.14	0.02	0.00	0.50

Lagerstroemia parviflora	0.09	0.37	0.37	0.40	0.07	1.29
Acacia catechu	0.06	0.16	0.16	0.02	0.02	0.42
Pinus roxburghii	0.13	1.24	3.91	8.97	8.00	22.25
Pinus wallichiana	0.02	0.24	0.94	1.41	0.49	3.10
Others	3.16	8.70	6.95	8.79	10.12	37.72
Total	7.14	28.84	31.25	40.02	36.20	143.45

In terms of quality class, the highest stem volume is observed in the high quality trees in larger stem sizes (22.96 m^3/ha and 22.30 m^3/ha) in DBH class > 50 cm and 30-50 cm, respectively. In contrary, the highest stem volume of cull trees is observed in smaller stem sizes (5.29 m^3/ha 14.30 m^3/ha) in DBH class 5-10 cm and 10-20 cm, respectively (Figure 9).

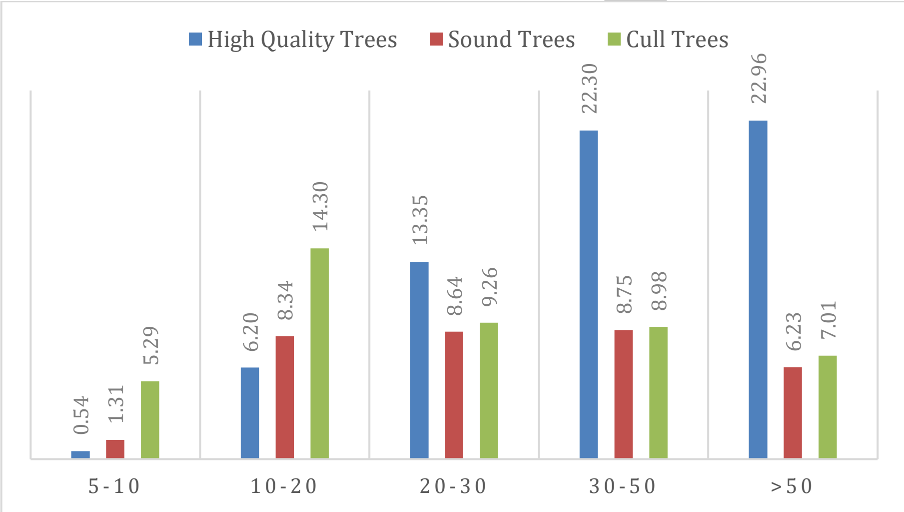

Figure 9: Stem volume by quality class and stem size

High-quality sound trees have the largest contribution (65.36 m^3/ha) of total stem volume in the Middle Mountain forests, followed by cull trees (44.83 m^3/ha) and sound trees (33.26 m^3/ha) (Table 16).

Table 16: Growing stock by quality class

Quality class	stems (No./ha)	basal area (m^2/ha)	stem volume (m^3/ha)	10 cm top volume (m^3/ha) (without bark)	20 cm top volume (m^3/ha) (without bark)
High-quality sound tree	136.72	7.33	65.36	47.02	38.23
Sound Tree	199.53	4.94	33.26	20.63	13.70
Cull Tree	602.30	8.51	44.83	24.03	14.90
TOTAL	**938.54**	**20.78**	**143.45**	**91.68**	**66.83**

The total stem volumes up to 10 cm top and up to 20 cm top diameters (under bark) are 91.68 m^3/ha and 66.83 m^3/ha. *Shorea robusta* comprises the highest (17.20 m^3/ha) for stem volume up to 10 cm top diameter whereas P*inus roxburghii* comprises the highest (13.84 m^3/ha) for stem volume up to 20 cm top diameter (Table 17).

Table 17: Stem volume without bark by species

SN	Species	Stem volume without bark (m^3/ha)		
		Total stem	Up to 10 cm top diameter	Up to 20 cm top diameter
1	*Shorea robusta*	20.42	17.20	10.29
2	*Rhododendron* species	5.99	4.74	3.32
3	*Quercus* species	12.54	11.71	9.35
4	*Schima wallichii*	6.77	5.82	3.71
5	*Castanopsis* species	5.45	4.46	3.08
6	*Lyonia* species	2.55	1.75	1.00
7	*Terminalia alata*	2.57	2.39	2.03
8	*Adina cordifolia*	0.56	0.52	0.44
9	*Mallotus philippensis*	0.36	0.18	0.06
10	*Lagerstroemia parviflora*	0.96	0.78	0.46
11	*Acacia catechu*	0.31	0.21	0.07
12	*Pinus roxburghii*	16.53	15.78	13.84
13	*Pinus wallichiana*	2.63	2.42	1.85
14	Others	29.38	23.72	17.32
Total		107.01	**91.68**	**66.83**

Regarding different management regimes, community forests hold the largest proportion in stem number. In terms of basal area and stem volume, higher proportion of growing stock is occupied by buffer zone community forests (Table 18).

Table 18: Growing stock by management regimes

Management Regime	***No of Plots***	***Number of stems/ha***	***Basal Area (m^2/ha)***	***Stem volume (m^3/Ha)***
Private Forest	*121*	*802.42*	*15.80*	*100.09*
Government Managed Forest	*182*	*901.94*	*21.83*	*146.10*
Protected Areas	*1*	*320.96*	*20.19*	*152.86*
Buffer zone CFUG	*3*	*676.85*	*26.06*	*205.90*
Conservation Area	*6*	*921.40*	*22.58*	*155.79*
Community Forests	*443*	*1004.02*	*21.98*	*156.33*
Leasehold Forest	*2*	*242.82*	*5.95*	*38.71*
Public Land Forest	*4*	*483.49*	*12.94*	*81.95*
Others	*9*	*809.80*	*10.18*	*55.73*
TOTAL	***771***	***938.54***	***20.78***	***143.45***

Stem volume without bark disaggregated by stem quality class and volume up to 10 and 20 cm top diameter is presented in

Table 19.

Table 19: Stem volume without bark per ha by species and quality class

Species Name	High quality sound tree			Sound tree			Cull trees		
	Stem	10 cm top	20cm top	Stem	10 cm top	20cm top	Stem	10 cm top	20cm top
Shorea robusta	11.9	10.66	6.97	5.77	4.7	2.43	2.75	1.85	0.89
Rhododendron species	0.16	0.15	0.13	0.77	0.69	0.55	5.06	3.9	2.65
Quercus species	4.12	4.07	3.86	3.69	3.5	2.71	4.73	4.14	2.77
Schimawallichii	2.43	2.27	1.57	2.16	1.79	1.08	2.18	1.75	1.06
Castanopsis species	1.07	0.89	0.59	1.73	1.44	0.97	2.65	2.14	1.51
Lyonia species	0.01	0.01	0	0.15	0.12	0.09	2.39	1.62	0.91
Terminalia alata	1.93	1.86	1.65	0.41	0.36	0.26	0.23	0.17	0.11
Adina cordifolia	0.38	0.37	0.35	0.11	0.09	0.06	0.08	0.06	0.04
Mallotus philippensis	0	0	0	0.08	0.04	0.02	0.27	0.13	0.04
Lagerstroemia parviflora	0.25	0.24	0.18	0.34	0.27	0.14	0.37	0.27	0.13
Acacia catechu	0.08	0.07	0.02	0.13	0.09	0.04	0.09	0.05	0.01
Pinus roxburghii	15.29	14.74	13.12	1.06	0.9	0.66	0.18	0.13	0.07
Pinus wallichiana	2.46	2.29	1.8	0.15	0.12	0.05	0.01	0.01	0
Others	9.96	9.4	7.99	7.82	6.51	4.64	11.6	7.81	4.7
Total	**50.03**	**47.02**	**38.23**	**24.37**	**20.63**	**13.7**	**32.61**	**24.03**	**14.9**

3.2.5 Biomass

The total air–dry biomass of middle mountain region is about (213.33 t/ha) 557.06 M t, equivalent to 506.44 M t of oven-dry biomass (193.94 t/ha), 80 % of the total aboveground biomass is represented by the live stems (164.46 t/ha), dead stems (1.03%), and deadwood (2.31%). Among the three components of live stem, stem and branch share around 63 % and 30% respectively (Table 20).

Table 20: Biomass in the Middle Mountain forests

Above Ground	Biomass Components	Air-dry Biomass (t/ha)
1.Live stem(a)	Stem	103.74
	Branch	49.98
	Foliage	10.74
Sub-total		**164.46**
2.Dead Stem (b)	Stem	2.15
	Branch	0.79
	Foliage	0
Sub-total		**2.94**
3.Dead Wood (c)		**3.26**
Total Aboveground biomass (AGB) (a+b+c)		**170.66**
Below ground biomass (BGB) (@ 25% of total AGB)		**42.67**
Total air-dry biomass (AGB + BGB)		**213.33**

Total oven-dry biomass (@ 90.90 % of the total air dry biomass)	**193.94**
Carbon (tree component in t/ha)	**91.15**

The highest air-dry biomass in stem component is found in *Shorea robusta* whereas the highest branch and foliage biomasses are both found in *Quercus* species (Table 21).

Table 21: Stem, branch and foliage biomass (air dry) by species

Species Name	Stem	Branch	Foliage	Total
Shorea robusta	25.69	5.61	1.64	32.93
Rhododendron species	5.06	4.05	1.23	10.35
Quercus species	12.58	11.95	2.68	27.20
Schima wallichii	8.06	2.56	0.37	10.99
Castanopsis species	5.31	4.22	0.26	9.79
Lyonia species	2.33	1.87	1.42	5.62
Terminalia alata	3.19	1.27	0.16	4.62
Adina cordifolia	0.50	0.20	0.03	0.73
Mallotus philippensis	0.34	0.14	0.02	0.50
Lagerstroemia parviflora	1.10	0.44	0.07	1.61
Acacia catechu	0.40	0.16	0.03	0.58
Pinus roxburghii	14.46	3.71	0.75	18.92
Pinus wallichiana	1.24	0.66	0.34	2.24
Others	23.48	13.17	1.75	38.40
Total	**103.74**	**49.98**	**10.74**	**164.47**

3.2.6 Carbon stock

Total carbon stock in the three major carbon pools of Middle Mountain forests is 384.20 M t C. The average carbon stock in forest is 147.13 t/ha. Out of all, tree component contains about 61.95%, followed by 36.93 % from soil organic carbon while the litter and debris component represents less than 2 % (Table 22).

Table 22: Forest carbon stock in different pools

Carbon pool	Carbon stock (t/ha)	Total carbon M t C
Tree component (=>5cm DBH)	91.15	238.02
Litter and debris	1.65 (to be updated later)	4.31 (to be updated later)
Soil organic carbon	54.33 (to be updated later)	141.87 (to be updated later)
Total carbon stock	**147.13** (to be updated later)	**384.20** (to be updated later)

3.2.7 Forest disturbances

Observing over 469 plots inside the Middle Mountain physiographic zone, 404 number of plots were found disturbed by multiple sources of disturbances. Predominant disturbances are livestock grazing, forest fire, tree cutting and lathra (pole/sapling) cutting. The livestock grazing (LG) disturbance was observed in the maximum number of plots (342) whereas wind/storm (WI) and plant disease (PD) were observed in the least number of plots (16 each) (Figure 10).

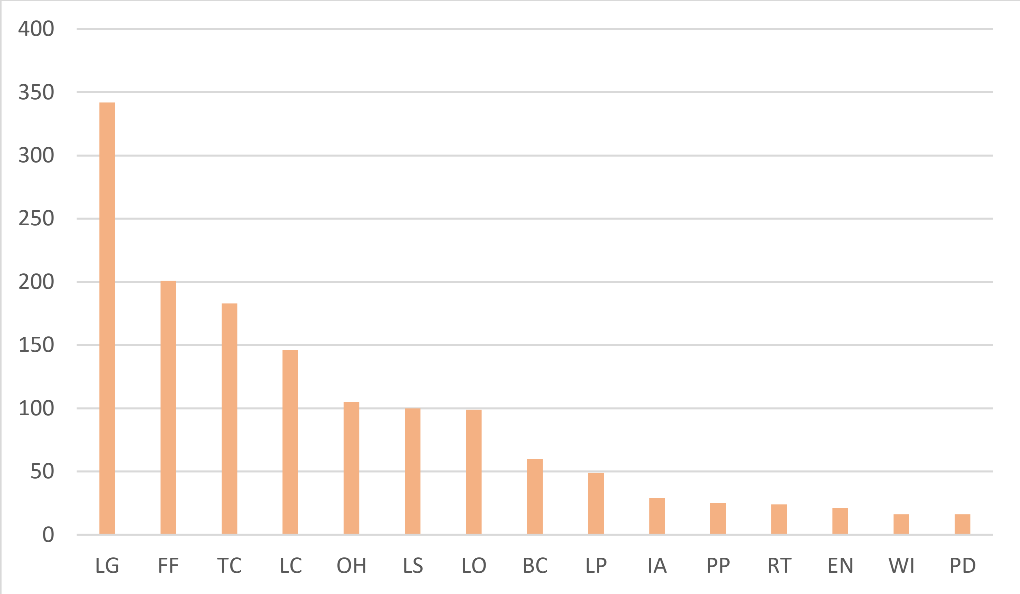

Figure 10: Disturbances found in different sample plots

Besides, anthropogenic disturbances like livestock grazing and tree cutting are observed up to around 11 km and 6.7 km from the forest edges while disturbances like encroachment and resin tapping are observed near to the settlements and other land uses (Figure 11).

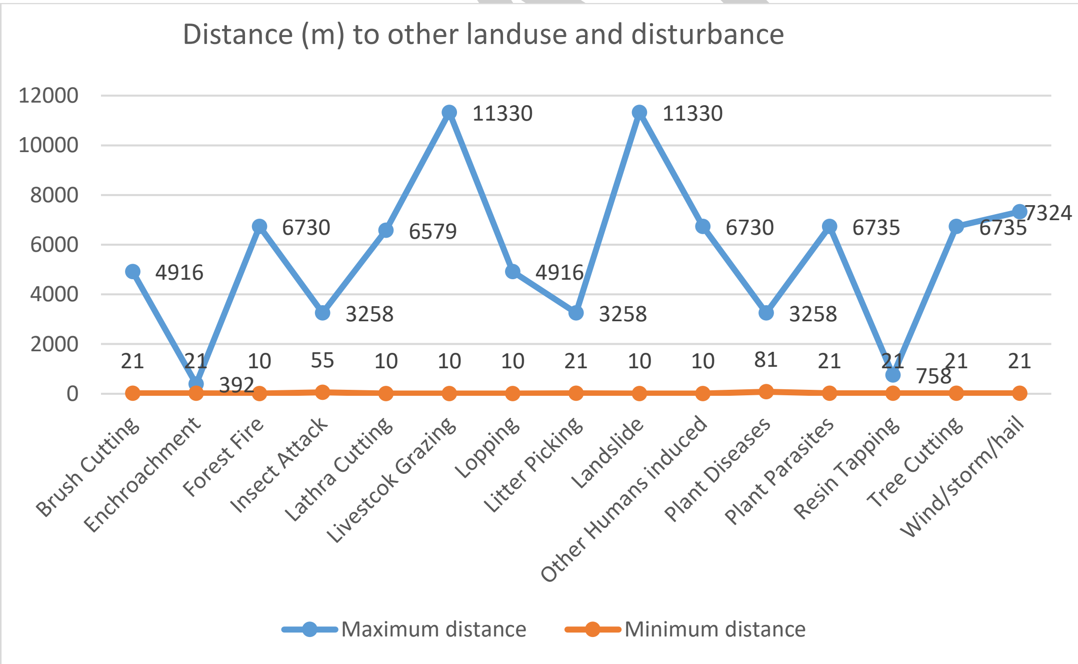

Figure 11: Forest disturbance and distance of sample plots to settlements and other land uses

A range of disturbances occurs in the Middle Mountain forests. Livestock grazing, tree cutting, forest fire, and sapling/pole cutting are the most prevalent disturbances occurring (Figure 12).

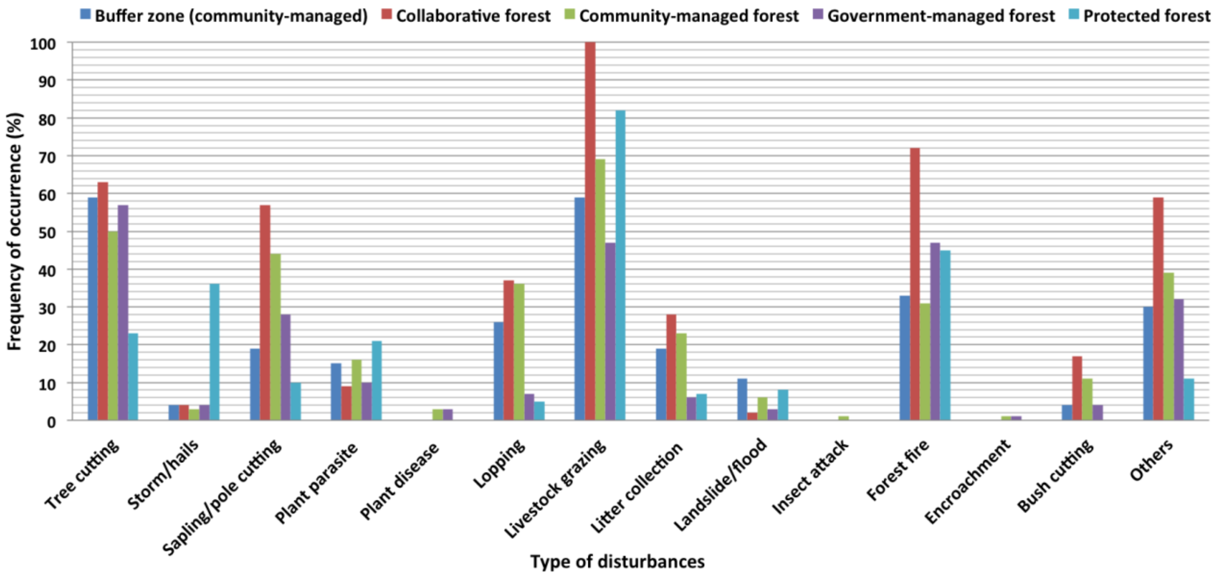

Figure 12: Occurrence of forest disturbances in different forest management regimes

Analysis of observation in PSPs showed that the frequency of different types of disturbances varies in different forest management regimes. Despite the differences in frequencies, all forest management regimes experienced some sort of disturbances (Figure 11).

3.2.8 Accuracy assessment

Different matrices for accuracy evaluation of derived forest inventory variables are presented in Table 23.

Table 23: Accuracy of results of some main variables

Description	Number of stems/ha	Basal area (m2/ha)	Stem volume (m3/ha)	Air-dry biomass (t/ha)	Carbon stock (t/ha)	SVWB up to 10 cm top dia.	SVWB up to 20 cm top dia.
Mean	938.54	20.77	143.41	164.42	91.65	91.65	66.83
Standard Error	43.38	0.75	5.51	7.77	4.44	4.44	4.25
% Error of Mean	4.62	3.63	3.84	4.73	4.84	4.84	6.36
Error at 95 % CI	9.06	7.12	7.53	9.26	9.49	9.49	12.46
Lower Limit at 95% CI	853.52	19.29	132.61	149.19	82.95	82.95	58.51
Upper Limit at 95% CI	1023.56	22.25	154.2	179.65	100.34	100.34	75.16

CI= confidence interval; dia = diameter; SVWB = Stem volume without bark

A separate accuracy assessment of the forest cover maps of Middle Mountain was not done as they were derived as a spatial subset of the national land cover map.

References

Acharya, K. P. 2003. Conserving biodiversity and improving livelihoods: The case of community forestry in Nepal. Paper presented in the International Conference on Rural Livelihoods, Forests and Biodiversity, 19–23 May, 2003, Bonn, Germany.

Altrell, D., Branthomme, A., and Tavani, R. n.d. Assessing Growing Stock and Stock Changes through Multi-purpose National Forest Monitoring and Assessment. www.fao.org/forestry/26100-03805443a729838ab9172b9f1b989b1ca.doc, accessed on December 2, 2013 (cited in DFRS, 2014).

Carson, B., Shah, P.B. and Maharjan, P.L. 1986. Land Systems Report: The Soil Landscapes of Nepal. Land Resources Mapping Project. Kenting Earth Sciences Limited.

Chaturvedi, A.N. 1982. Forest Mensuration. International Book Distributors, Dehradun, India.

Cochran, W.G. 1977. Sampling Techniques (3rd ed.). New York. John Wiley and Sons, Inc.

DFRS (2014). Middle Mountain Forests of Nepal (2010 – 2012). Babarmahal, Kathmandu: Forest Resource Assessment Nepal Project/Department of Forest Research and Survey.

Dijkshoorn, J. A. and Huting J. R. M. 2009. Soil and Terrain Database for Nepal. Report 2009/01 (available through: http://www.isric.org), ISRIC, World Soil Information, Wageningen, The Netherlands.

FAO 2006. Guidelines for soil description (4th ed.). Food and Agriculture Organisation of the United Nations, Publishing Management Service, Information Division, Rome, Italy.

FRTC, 2022. National Land Cover Monitoring System of Nepal. Forest Research and Training Centre (FRTC). Kathmandu, Nepal.

Gering, L.R. 1995. The Relationship of Diameter at Breast Height and Crown Diameter for Four Species Groups in Hardin County, Tennessee. *Southern Journal of Applied Forestry*, Vol. 19 (4).

Heinonen, J., Saramaki, J. and Sekeli, P.M. 1996. A Polynomial Taper Curve Function for Zambian Exotic Tree Plantations. Journal of Tropical Forest Science, 8 (3): 339–354

IPCC 2006. Good Practice Guidance for National Greenhouse Inventories. Agriculture, Forestry and Other Land Uses (Vol. 4). Geneva, Switzerland.

ISRIC 2009. SOTER database for LADA partners countries (http://www.isric.org/UK/About+Soils/Soil+data/Geographic+data/National/default.htm).

Jackson, J. K. 1994. Manual of Afforestation in Nepal. Nepal-United Kingdom Forestry Research Project. Forest Survey and Research Office, Department of Forests, Kathmandu, Nepal.

JAFTA 2001. Activity Report of Wide Area Tropical Forest Resources Survey (Kingdom of Nepal). Japan Forest Technology Association, Information System Development Project for the Management of Tropical Forests.

Jones C., Gregory J., Thorpe R., Cox P., Murphy J., Sexton D. and Valdes, H. 2004. Systematic Optimisation and Climate Simulation of FAMOUS, a Fast Version of HADCM3 (Hadley Centre Technical Note No. 60). (http:==www.metoffice.gov.uk=research=hadleycentre=pubs=HCTN=HCTN_60.pdf).

Kharal, D. K. and Fujiwara, T. 2012. Growth and yield estimation of*Chamaecyparis spp*. through tree ring analysis. Banko Janakari 22 (2): 36-42.

Kleinn, C. 1994. Forest Resources Inventories in Nepal Status, Quo, Needs, Recommendations. FRISP, HMGN/FINNIDA.

LRMP 1986. Land System Report, Land Resource Mapping Project: Kenting Earth Science, Canada.

Mehtatalo Lauri and Kansanen Kasper (2020). lmfor: Functions for Forest Biometrics. R package version 1.5. https://CRAN.R-project.org/package=lmfor

MFSC 1988. Master Plan for the Forestry Sector in Nepal. Kathmandu, Nepal.

Pribyl, D.W. 2010. A Critical Review of the Conventional SOC to SOM conversion factor. Geoderma, 156: 75-83.

Sharma, E.R. and Pukkala, T. 1990. Volume Equations and Biomass Prediction of Forest Trees of Nepal (Publication No. 47). Kathmandu, Nepal: Forest Survey and Statistics Division, Kathmandu.

Survey Department. 2001. National Topographical Base Maps. Kathmandu, Nepal.

Walkley, A.J. and Black, I.A. (1934) Estimation of soil organic carbon by the chromic acid titration method. Soil Sci. 37, 29-38.

WECS. 2011. Water Resources of Nepal in the Context of Climate Change. Aryal, R. S. and Gautam, R. (eds.). Water and Energy Commission Secretariat, Kathmandu, Nepal.

Annex-1: Summary of diameter-height model

SN	Species	Model	Equation	a	b	SE (a)	SE(b)
1	*Acacia*	Naslund	h(d) = bh + d^2/(a + b d)^2	0.9994504	0.2326059	0.26	0.01
2	*Adina*	Curtis	h(d) = bh + a (d/(1 + d))^b	25.42872	18.48454	3.26	3.47
3	*Aesandra*	Naslund	h(d) = bh + d^2/(a + b d)^2	3.1492906	0.1720515	0.41	0.02
4	*Albizzia*	Curtis	h(d) = bh + a (d/(1 + d))^b	29.63829	19.04946	2.70	2.08
5	*Alnus*	Naslund	h(d) = bh + d^2/(a + b d)^2	1.8352060	0.1770947	0.17	0.01
6	*Bombax*	Naslund	h(d) = bh + d^2/(a + b d)^2	2.5425990	0.1644107	0.39	0.01
7	*Castanopsis*	Naslund	h(d) = bh + d^2/(a + b d)^2	1.6165093	0.2283902	0.12	0.01
8	*Cleistocalyx*	Naslund	h(d) = bh + d^2/(a + b d)^2	2.3618081	0.2099419	0.40	0.02
9	*Dalbergia*	Curtis	h(d) = bh + a (d/(1 + d))^b	10.870580	7.201138	4.21	1.72
10	*Desmodium*	Curtis	h(d) = bh + a (d/(1 + d))^b	16.10976	12.04966	2.17	1.60
11	*Diospyrus*	Naslund	h(d) = bh + d^2/(a + b d)^2	1.4765318	0.2602529	0.14	0.02
12	*Eurya*	Curtis	h(d) = bh + a (d/(1 + d))^b	14.152664	7.901654	1.20	1.13
13	*Ficus*	Naslund	h(d) = bh + d^2/(a + b d)^2	2.7857384	0.2437675	0.36	0.01
14	*Lagerstromia*	Michailoff	h(d) = bh + a e^(-b d^(-1))	20.46322	12.24723	2.06	1.76
15	*Litsea*	Naslund	h(d) = bh + d^2/(a + b d)^2	1.7333760	0.2441696	0.32	0.02
16	*Lyonia*	Naslund	h(d) = bh + d^2/(a + b d)^2	1.9341248	0.2714268	0.19	0.01
17	*Myrica*	Naslund	h(d) = bh + d^2/(a + b d)^2	1.8020695	0.2549256	0.19	0.01
18	*Pinus*	Naslund	h(d) = bh + d^2/(a + b d)^2	3.267958	0.137201	0.18	0.01
19	*Quercus*	Curtis	h(d) = bh + a (d/(1 + d))^b	18.44365	14.55401	1.44	1.38
20	*Rhododendron*	Naslund	h(d) = bh + d^2/(a + b d)^2	2.1289182	0.2605115	0.15	0.01
21	*Sapium*	Naslund	h(d) = bh + d^2/(a + b d)^2	2.3520042	0.2139059	0.36	0.02
22	*Schima*	Curtis	h(d) = bh + a (d/(1 + d))^b	20.20930	11.62445	0.70	0.59
23	*Shorea*	Curtis	h(d) = bh + a (d/(1 + d))^b	24.39227	13.29688	0.72	0.48
24	*Syzygium*	Meyer	h(d) = bh + a (1-exp(-b d))	16.832977	0.044183	1.77	0.01
25	*Terminalia*	Naslund	h(d) = bh + d^2/(a + b d)^2	2.4066873	0.1633199	0.24	0.01
26	Miscellaneous	Curtis	h(d) = bh + a (d/(1 + d))^b	20.04740	13.16643	0.65	0.63

Annex-2: Derivation of volume ratio for trees having broken top

v = vf * (vcut.int/vtot.int),

where:

v = predicted stem volume (dm^3)

vf = volume (dm^3) predicted using models of Sharma and Pukkala (1990) and total height predicted using the height generalisation model for FRA

vcut.int = stem volume (dm^3) from stump height (15 cm) to the cut point of tree

vtot.int = stem volume (dm^3) from stump height (15 cm) to the tip of tree

Also,

a1-a3 = parameters of correction polynomial

b1-b8 = parameters of the relative taper curve (population mean) model, i.e. so-called *Fibonacci curve*.