HIGH MOUNTAINS AND HIGH HIMAL FORESTS OF NEPAL

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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 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
C	Carbon
CCSP	Concentric Circular Sample Plot
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
HH	High Himal
HM	High Mountains
LMH	Lower Mixed Hardwood
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
SOC	Soil Organic Carbon
SOP	Standard Operating Procedure
SVWB	Stem Volume Without Bark
Tg	Teragram (1 Tg = $1X10^{12}$ g)
UMH	Upper 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%, including the 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.
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.

Main Results

Forest cover

- Forest and Other Wooded Land (OWL) cover 27.63% (1,817,290 ha) and 4.91% (323,182 ha), respectively, of the total area of the high mountains and high Himal physiographic region. Thus, forest and OWL together cover 32.54% of the total area in the region.

Growing Stock

- The high mountains and high Himal forest contain a total of 1891.07 million (1040.6 per ha) live stems (≥ 5cm DBH). The number of standing dead stems (≥ 5cm DBH) was 89.37 million (49.18 per ha).
- The total volume of live stems (DBH >= 5 cm) in the hand High Himal forests is 421.66 million m^3 (232.03 m^3/ha).
- *Rhododendron* spp. constitutes largest stem volume per ha (239.45 m^3/ha) in the High mountains and High Himal forests, followed by *Quercus* spp. (158.33 m^3/ha).
- The total stem volume and volume of stems up to 10 cm top diameter and up to 20 cm top diameter without bark are 190.73, 173.63 and 148.56 cubic meters per hectare respectively
- The High Mountains and High Himal forests contain a total of 746.54 million tons of air-dry biomass (410.80 t/ha), equivalent to 678.68 million tons of oven-dry biomass (373.46 t/ha).

Carbon stock

Total carbon stock in the three major carbon pools of High Mountains and High Himal forests is 539.23 million t C. The average carbon stock in forest is 296.72 t/ha.

Disturbances

Livestock grazing, tree cutting, forest fire, and sapling/pole cutting are the most prevalent disturbances occurring in high mountains and high Himal forest.

Executive Summary

This report presents the results of a forest resource assessment carried out in the High Mountains and High Himal physiographic region of Nepal between 2019 to 2021. Altogether 637 plots (566 in High Mountains and 71 in High Himal) were measured during the field assessment. 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 total land (6,576,191 ha) area in the High Mountains and High Himal physiographic region, 'forest' and 'other wooded land (OWL)' covers 27.63% (1,817,290 ha) and 4.91% (323,182 ha), respectively. Thus, forest and OWL together covers 32.54% of the total area in the region. The assessment reveals that the High Mountains and High Himal forest contains a total of 1,891.07 million (1040.6 per ha) live stems (≥ 5cm DBH). Similarly, the number of standing dead stems (≥ 5cm DBH) is 89.37 million (49.18 per ha). The stem volume in the High Mountains and High Himal forest is (232.03 m^3/ha). *Rhododendron* spp. constitutes the largest stem volume per ha (239.45 m^3/ha), followed by *Quercus* spp. (158.33 m^3/ha). The total stem volume and volume of stems up to 10 cm top diameter and up to 20 cm top diameter without bark are 190.73, 173.63 and 148.56 m^3 per hectare respectively. The High Mountains and High Himal forest contain 410.80 t/ha of air-dry biomass, equivalent to 373.46 t/ha of oven-dry biomass. Similarly, the regions contain 296.72 t/ha of carbon stock. Livestock grazing, tree cutting, forest fire, and sapling/pole cutting are the most prevalent disturbances occurring in High Mountains and High Himal forests.

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CHAPTER 1: INTRODUCTION

1.1. Background

The Forest Resource Assessment (FRA) Nepal Project (2010-2014) conducted a comprehensive assessment of the High Mountains and High Himal forests between 2010 and 2014 (DFRS, 2014). The project had established 468 permanent sample plots (PSPs) during the project period. Later, in addition to the remeasurement of those PSPs, Forest Research and Training Centre (FRTC) established additional 170 PSPs (145 in High Mountains and 25 in High Himal regions) in 2020 to 2022 to enhance the precision of the forest inventory results of these physiographic regions. This assessment presents the combined result of the High Mountains and High Himal: 1) forest statistics based on the measurement of total 637 plots between 2020 and 2022, and 2) the area statistics of forests and other wooded land (OWL) based on the National Land Cover Monitoring System (FRTC, 2022).

1.2. The Environment of the High Mountains and High Himal Forests

The High Mountains (HM) physiographic region, lies in the north of Middle Mountains region and in the South of High Himal (HH) physiographic region. High Mountains region extends over geomorphic units of Midlands in the Lesser Himalayan Tectonic Zone and Fore Himalaya in the Higher Himalayan Tectonic Zone (Upreti, 1999). The High Himal physiographic region lies in the northern most part of the country and consists of range of larger mountain. Spatially, High Mountains region extends from 80° 30’ 47” to 88° 07’ 04” E longitude; and from 26° 59’ 15” to 30° 06’ 47” N latitude (Figure 1). The region occupies 3,009,210 ha i.e. 20.4% of the total land area of the country and covers parts of 40 districts. The elevation of High Mountains region varies from 543 m in the river valley floors to 4,951 m above mean sea level with rugged landscape and very steep slopes. Similarly, High Himal region extends from 80° 45’ 10” to 88° 12’ 22” E longitude; and from 27° 22’ 54” to 30° 27’ 01” N latitude covering 3,533,947 ha i.e. 23.9% of the total land area and covers parts of 25 districts. The elevation of these regions ranges from 1,960 m to 8,848 m (Figure 1).

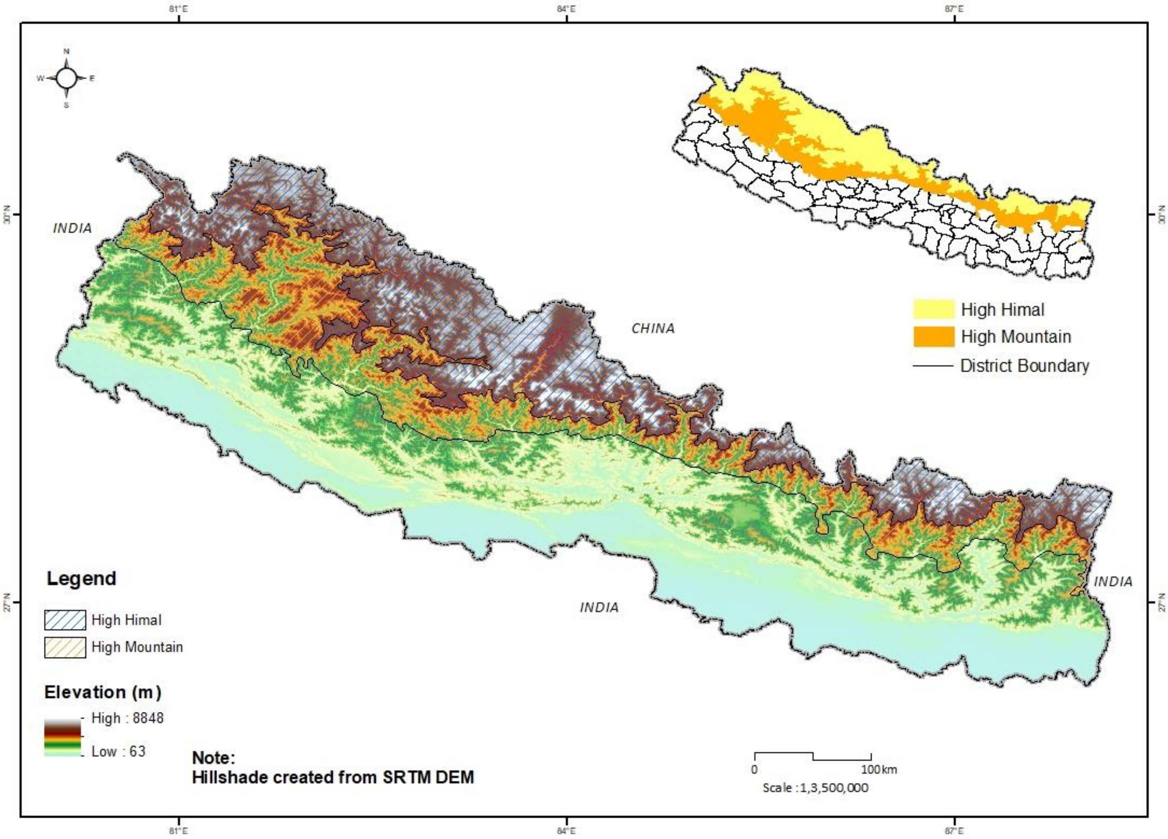

Figure 1: The spatial extent of the High Mountains and High Himal in Nepal

The Midlands geomorphologic units of High Mountains vary in width from 40–60 km and are composed of schist, phyllite, gneiss, quartzite, granite, limestone rocks dating back to Precambrian and Paleozoic to Mesozoic period. The Fore Himalaya geomorphic units vary in width from 20–70 km and are composed of gneiss, schist and marble mostly belonging to the northern edge of the Lesser Himalayas dating to Precambrian period (Upreti, 1999).

Soils

High Mountains region has more metamorphosed and structurally consolidated rocks. Most of the major valleys have been glaciated. High river gradients and enhanced river down-cutting resulted in the formation of deep canyons (Pariyar, 2008). High Himal physiographic region has about 24% of permanently snow covered area. The mountains are very steep with active glacier systems. The geology consists of gneiss, schist, limestone and shale of different ages. Physical weathering predominates and soils are very stony. Characteristic landforms are glaciers, cirque basins, moraines, U-shaped valleys and avalanche slopes. Bedrock in most of the exposed at or near the surface. Less than 1% of the region has soil and climate suited to crop production and then only where irrigation is available. Soil formation on the slopes is slow and soils are rocky (Pariyar, 2008).

Climate

The climate in High Mountains region is quite varied because of strong influence of local mountains on rainfall distribution and incident solar radiation. Areas in the rain shadow (leeward side of Annapurna and Dhaulagiri mountain ranges) receive much less rainfall and have drier climatic conditions. The climatic regime ranges from warm-temperate in the valleys to cool-temperate in the higher hills and Arctic in the mountainous region. The average annual maximum temperature[1] is about 20°C (ranging from -12°C to 36°C); with the average annual minimum 7°C (ranging from -18°C to 30°C) in the region. Precipitation[2] in the region varies from east to west with the highest in Central Development Region with total annual precipitation of 2,185 mm, followed by Eastern Development Region with total annual precipitation of 2,100 mm, Far-Western with total annual precipitation of 2,032 mm, Western with 1,681 mm and Mid-Western with 1,054 mm. Some regions of Mustang and Dolpa districts receive the lowest precipitation (379 mm and 482 mm respectively), while some regions of Kaski receive the highest (3,585 mm) precipitation.

Drainage

High Mountains and High Himal regions are the origin of first-grade rivers of Nepal. These rivers are snow-fed and flow across all the physiographic regions. The first-grade rivers that originate in the Himalayas are Mahakali, Karnali, Narayani and Sapta-Koshi. This region is the major source of water for Nepal as well as whole Gangetic region.

1.3. Forest Resource Assessment (2010-2014)

The recent and most comprehensive nationwide forest resource assessment (FRA) was carried out 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) to provide 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 (the systematic sampling of cluster plots) and took into account national data needs as assessed in 2010. Five physiographic strata, i.e. the Terai, Churia, Middle Mountains, High Mountains and High Himal, were considered for the assessment. However, due to fewer number of sample plots in High Himal region, combine report of High Himal and High Mountains is going to published in this report. The last assessment in the High Mountains and High Himal physiographic region was carried out between 2012 and 2014 as part of national forest inventory. It revealed that the forest and other wooded land was 1,922,909 ha (29.36%) and 553,431 ha (8.45%) of total land area of the region respectively (DFRS, 2015).

[1] Temperature data is based on average monthly temperatures (1957—2013) of 22 DHM stations.
[2] Precipitation data is based on total average precipitations (1950—2013) of 64 DHM stations.

CHAPTER 2: METHODOLOGY

2.1 Introduction

The forest resource assessment in the High Mountains and High Himal physiographic region included remeasurement of existing 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.

2.2Forest 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 finalised by the then DFRS (Figure 2).

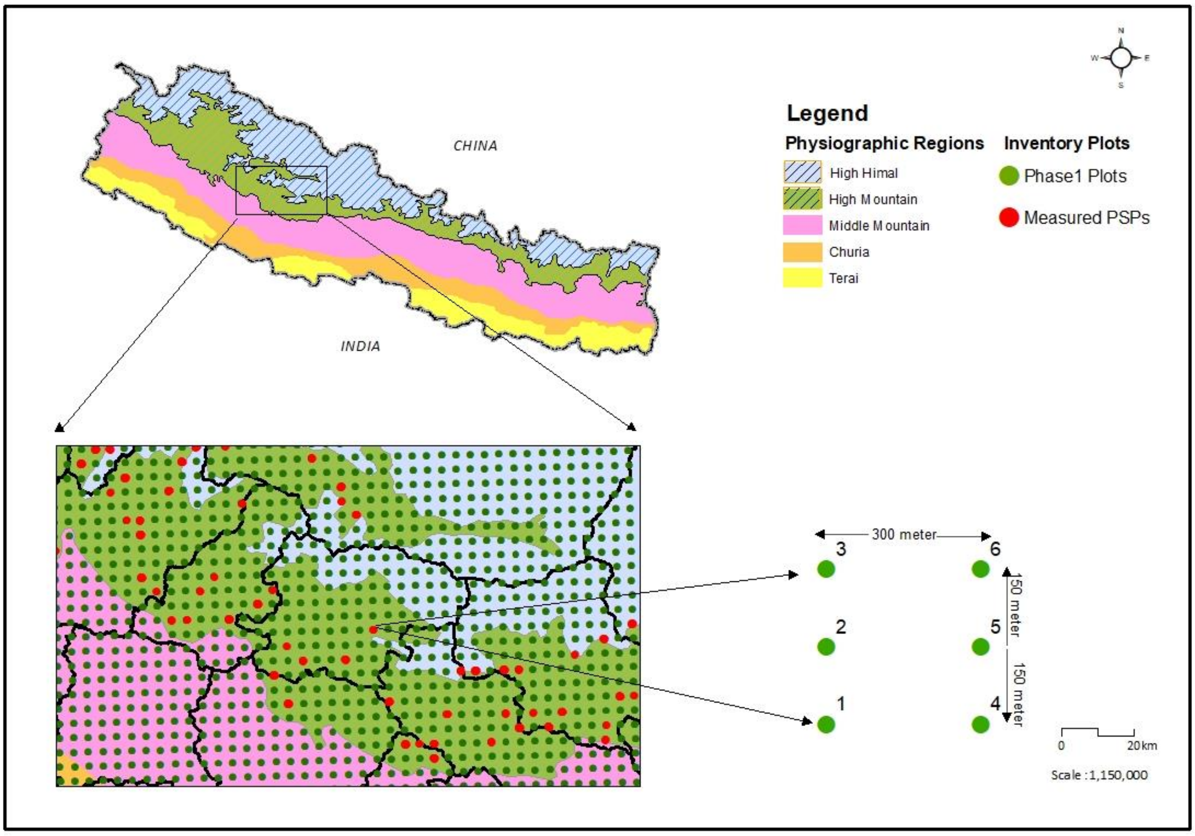

Figure 2: Layout of the clusters and plot within each cluster

The detailed methodology adopted for sample selection is presented in DFRS, 2014. Altogether 637 plots (421 PSPs in High Mountains and 46 PSPs in High Himal in addition to 145 PSPs in High Mountains and 25 PSPs in High Himal) were selected for the second phase field measurement (Figure 3).

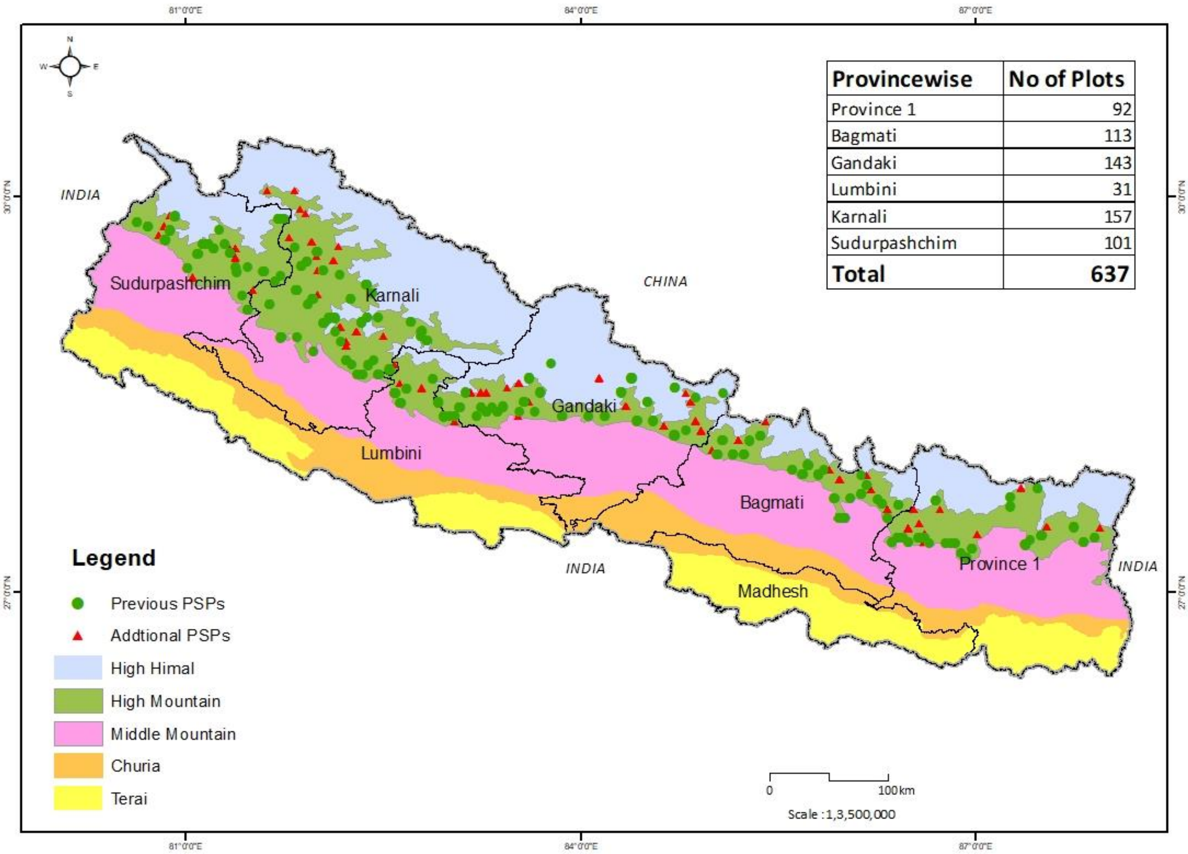

Figure 3: Distribution of permanent sample plots

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 center 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 center in the four cardinal directions. Dead and decaying wood was assessed in a circular plot with a radius of 10 m from the plot center. 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.

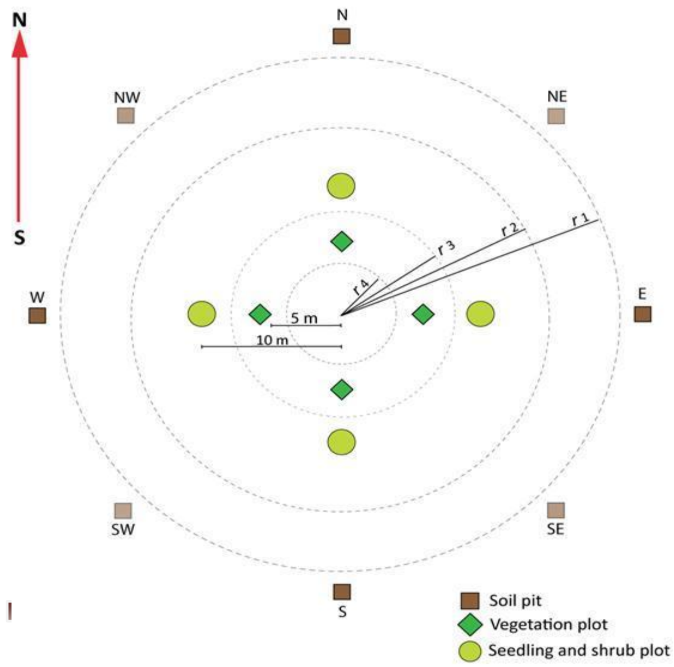

Figure 4: Layout of the concentric circular plot with other sub-plots

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. For the statistical analysis to check for the quality of the results, over 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 Naslund function (Equation 1) implemented in the R package *Lmfor* (Mehtatalo, 2012).

Equation 1: Naslund function for height imputation:

$$h(d) = bh + d^2/(a + b\,d)^2$$

where,

d	A vector of tree diameters, usually in cm
h	A vector of tree heights, usually in m.
a, b	Parameters a, b of the applied function.
bh	The applied height for measuring tree diameter (breast height), in m.

The details of the model parameters are listed in Annex 1.

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 2: Tree volume

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

where,

ln = Natural logarithm to the base 2.71828.

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

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 for Equation 2 are presented in Table 1.

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

Species	a	b	c
Abies spp.	-2.4453	1.7220	1.0757
Acer spp.	-2.3204	1.8507	0.8223
Albizia spp.	-2.4284	1.7609	0.9662
Alnus nepalensis	-2.7761	1.9006	0.9428
Anogeissus latifolia	-2.2720	1.7499	0.9174
Betula utilis	-2.3204	1.8507	0.8223
Bombax ceiba	-2.3865	1.7414	1.0063
Castanopsis spp.	-2.3204	1.8507	0.8223
Toona ciliata	-2.1832	1.8679	0.7569
Cedrus deodara	-2.3204	1.8507	0.8223
Cupressus torulosa	-2.3204	1.8507	0.8223
Dalbergia sissoo	-2.1959	1.6567	0.9899
Daphniphyllum himalayense	-2.3204	1.8507	0.8223
Diospyros spp.	-2.3204	1.8507	0.8223
Engelhardia spicata	-2.3204	1.8507	0.8223
Syzygium cumini	-2.5693	1.8816	0.8498
Juniperus indica	-2.3204	1.8507	0.8223
Lagerstroemia parviflora	-2.3411	1.7246	0.9702
Larix griffithiana	-2.3204	1.8507	0.8223
Litsea spp.	-2.3204	1.8507	0.8223
Lyonia spp.	-2.3204	1.8507	0.8223
Magnolia champaca	-2.0152	1.8555	0.7630
Myrica spp.	-2.3204	1.8507	0.8223
Pinus roxburghii	-2.9770	1.9235	1.0019
Pinus wallichiana	-2.8195	1.7250	1.1623
Pyrus pashia	-2.3204	1.8507	0.8223
Quercus spp.	-2.3600	1.9680	0.7469
Rhododendron spp.	-2.3204	1.8507	0.8223

Rhus spp.	-2.3204	1.8507	0.8223
Shorea robusta	-2.4554	1.9026	0.8352
Schima wallichii	-2.7385	1.8155	1.0072
Terminalia alata	-2.4616	1.8497	0.8800
Tsuga spp.	-2.5293	1.7815	1.0369
Miscellaneous in Hill	-2.3204	1.8507	0.8223

Source: Sharma and Pukkala (1990)

The total volumes of broken trees were 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 3 (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 3: 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 High Mountains and High Himal trees

Species	Air-dried density (kg/m^3)
Abies spp.	480
Acer spp.	640
Albizia spp.	673
Alnus nepalensis	390
Anogeissus latifolia	880
Betula utilis	700
Bombax ceiba	368
Castanopsis spp.	740
Toona ciliate	480
Cedrus deodara	560
Cupressus torulosa	600
Dalbergia sissoo	780
Daphniphyllum himalayense	640
Diospyros spp.	840
Engelhardia spicata	674
Syzygium cumini	770
Juniperus indica	500
Lagerstroemia parviflora	850
Larix griffithiana	510
Litsea spp.	610
Lyonia spp.	674
Magnolia champaca	497
Myrica spp.	750

Pinus roxburghii	650
Pinus wallichiana	400
Pyrus pashia	674
Quercus spp.	860
Rhododendron spp.	640
Rhus spp.	674
Shorea robusta	880
Schima wallichii	689
Terminalia alata	950
Tsuga spp.	450
Miscellaneous in Hill	674

Source: Sharma and Pukkala (1990)

Tree branch and foliage biomass estimation:

Separate branch-to-stem and foliage-to-stem biomass ratios for *Abies* spp., *Cedrus deodara* and the other UMH species mentioned in the MFSC (1988) for small (DBH < 28 cm), medium (DBH 28 – 53 cm) and large (DBH > 53 cm) trees were used to estimate branch and foliage biomass from stem biomass (Table 3). Dead trees were not taken into account for this estimate.

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

Species	Branch-to-stem			Foliage-to-stem		
	Small	Medium	Big	Small	Medium	Big
Abies spp.	0.44	0.37	0.36	0.25	0.14	0.11
Acer spp.	0.75	0.99	1.16	0.21	0.18	0.18
Albizia spp.	0.40	0.40	0.40	0.07	0.05	0.04
Alnus nepalensis	0.80	1.23	1.51	0.17	0.09	0.06
Anogeissus latifolia	0.40	0.40	0.40	0.07	0.05	0.04
Betula utilis	0.75	0.99	1.16	0.21	0.18	0.18
Bombax ceiba	0.40	0.40	0.40	0.07	0.05	0.04
Castanopsis spp.	0.40	0.92	1.50	0.05	0.05	0.04
Toona ciliata	0.40	0.40	0.40	0.07	0.05	0.04
Cedrus deodara	0.44	0.37	0.36	0.25	0.14	0.11
Cupressus torulosa	0.40	0.40	0.40	0.07	0.05	0.04
Dalbergia sissoo	0.68	0.68	0.68	0.01	0.01	0.01
Daphniphyllum himalayense	0.75	0.99	1.16	0.21	0.18	0.18
Diospyros spp.	0.75	0.99	1.16	0.21	0.18	0.18
Engelhardia spicata	0.93	1.41	1.69	0.32	0.23	0.20
Syzygium cumini	0.40	0.40	0.40	0.07	0.05	0.04
Juniperus indica	0.40	0.40	0.40	0.07	0.05	0.04
Lagerstroemia parviflora	0.40	0.40	0.40	0.07	0.05	0.04
Larix griffithiana	0.44	0.37	0.36	0.25	0.14	0.11
Litsea spp.	0.40	0.40	0.40	0.07	0.05	0.04
Lyonia spp.	0.88	0.71	0.67	0.51	0.71	0.85
Magnolia champaca	0.40	0.40	0.40	0.07	0.05	0.04
Myrica spp.	0.52	0.59	0.61	0.17	0.16	0.16

Pinus roxburghii	0.19	0.26	0.30	0.10	0.05	0.03
Pinus wallichiana	0.68	0.49	0.41	0.40	0.24	0.18
Pyrus pashia	1.60	2.68	3.22	0.19	0.17	0.17
Quercus spp.	0.75	0.96	1.06	0.23	0.22	0.20
Rhododendron spp.	0.54	0.91	1.14	0.28	0.23	0.21
Rhus spp.	0.60	0.63	0.64	0.14	0.08	0.08
Shorea robusta	0.06	0.34	0.36	0.06	0.07	0.07
Schima wallichii	0.52	0.19	0.17	0.06	0.04	0.03
Terminalia alata	0.40	0.40	0.40	0.07	0.05	0.04
Tsuga spp.	0.44	0.37	0.36	0.25	0.14	0.11
Miscellaneous in Hill	0.40	0.40	0.40	0.07	0.05	0.04

Source: MFSC (1988)

The total biomass of individual trees was estimated using Equation 4.

Equation 4: 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 5 (Altrell *et al.,* n.d.).

Equation 5: 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 6) proposed by Cochran (1977).

Equation 6: 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 High Mountains and High Himal 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 of 2019 using decision trees, and finally, validation and accuracy assessment (Figure 5).

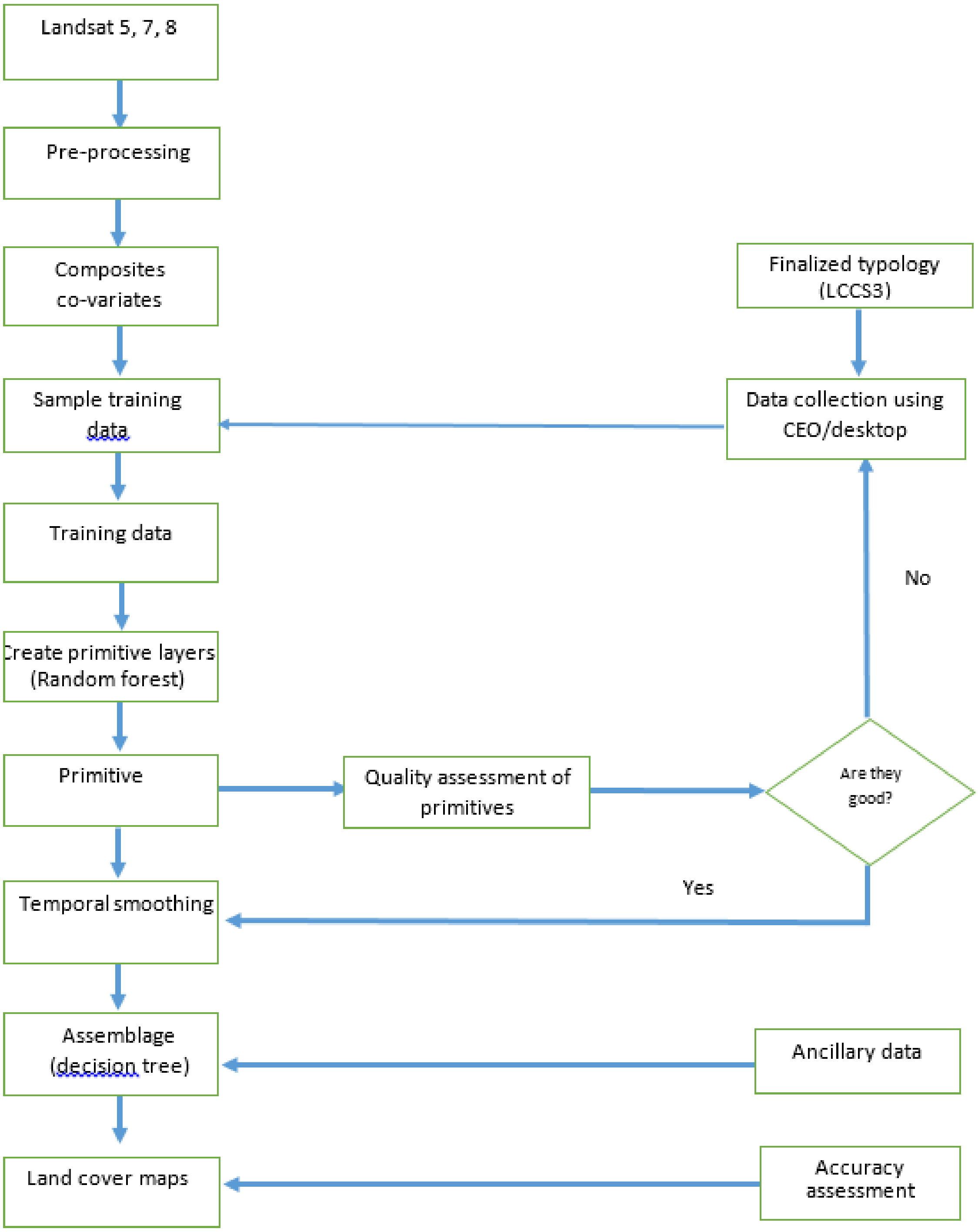

Figure 5: A flowchart showing the overall method of the NLCMS

2.4 Forest soil assessment

Soil samples were collected from the top 30cm soil layer in each plot and analysed 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-center towards the four sub-cardinal directions, i.e. alternative soil pits, as shown in Figure 5. 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^2 area (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).

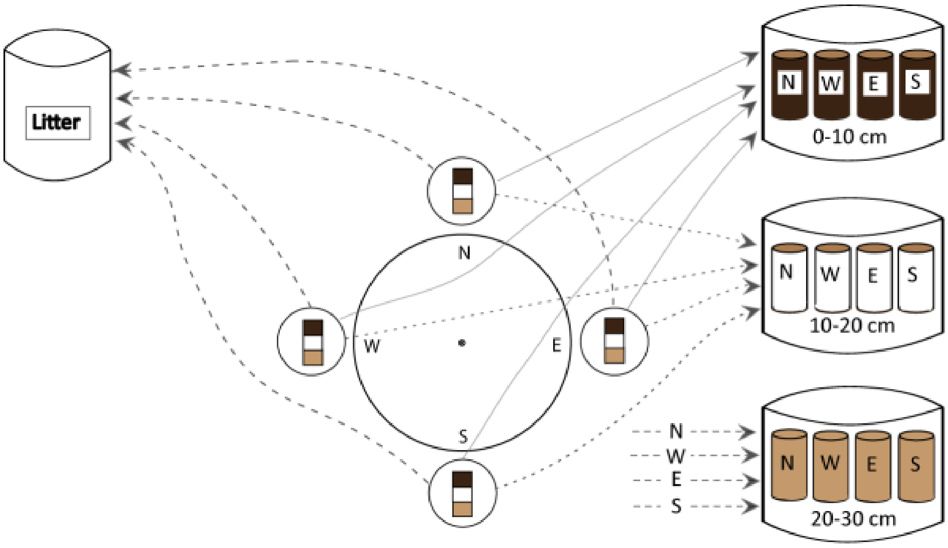

Figure 6: Collection of composite samples of litter, debris and soil from a plot

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 High Mountains and High Himal 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 impact the precision of estimating above and belowground wood biomass and carbon content in the High Mountains and High Himal 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 High Mountains and High Himal 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 High Mountains and High Himal forest

Forest and Other Wooded Land (OWL) occupy 27.63 % (1,817,290 ha) and 4.91 % (323,182 ha) of the total area of the High Mountains and High Himal region, respectively. Thus, Forest and OWL together cover 32.54 % of the total land cover of the region (Table 4).

Table 4: Land cover in the High Mountains and High Himal, 2019

Land cover class	Area	
	Ha	%
Forest	1,817,290	27.63
Other Wooded Land (OWL)	323,182	4.91
Other land	4,435,719	67.46
Total	**6,576,191**	**100**

The land cover map of the High Mountains and High Himal region is presented in (Figure 7).

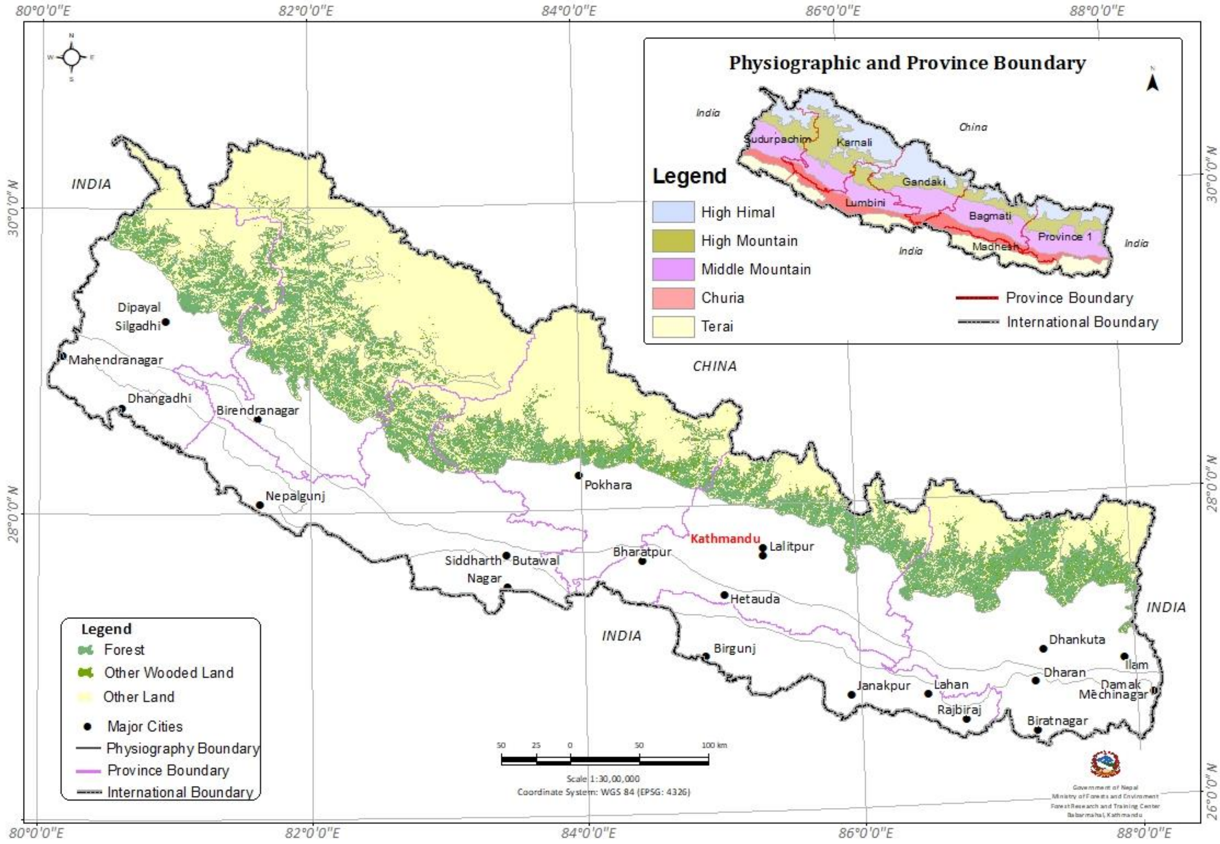

Figure 7: Land cover map of the High Mountain and High Himal region, 2019

3.2. High Mountains and High Himal 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, regeneration (seedling/sapling), biodiversity, etc. are also included. The species that contribute one percent or above to the total growing stock of the High Mountains and High Himal forests are included in the result tables and graphs.

3.2.1 Number of stems (DBH>=5 cm)

The High Mountains and High Himal forests of Nepal contain a total of 1,891.07 million live stems with DBH>=5cm, the average number of stems being 1,040.6 per hectare. There are 89.37 million standing dead stems (49.18 per hectare), of which more than 90 percent are usable. Co-dominant stems constitute the highest proportion of stems in the High Mountains and High Himal forests, followed by intermediate ones. About 88.65 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

Tree Status	Crown class	No of trees/ha
Live trees	Dominant	265.22
	Co-dominant	352.67
	Intermediate	288.11
	Suppressed	36.56
	Understory	26.98
	Top Cut	71.07
	Total	**1040.60**
Standing Dead Trees	Dead Usable	45.94
	Dead Unusable	3.24
	Total	**49.18**
	Removed	**88.65**
	Grand Total	**1178.42**

Rhododendron spp. is the most abundant species group in the High Mountains and High Himal forests (239.45/ha), followed by *Quercus* spp. (158.33 /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 484.08, 375.04, 95.03 and 57.23, respectively. The average weighted DBH and height of stems are 92.02 cm and 15.84 m, respectively, with *Tsuga* spp. having the largest ones (Average weighted diameter is 96.86 cm and Average weighted height is 26.50 m) (Table 6).

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

		No of stems per ha DBH class (cm)							
SN	**Species Name**	**5-10**	**10-20**	**20-30**	**30-50**	**>50**	**Total**	**Average Weighted DBH (cm)**	**Average Weighted Height (m)**
1	*Abies* spp.	5.62	6.95	3.98	4.14	2.79	23.47	75.29	23.90
2	*Alnus nepalensis*	2.19	3.44	2.69	2.47	1.19	11.97	52.72	21.88
3	*Betula utilis*	2.81	5.70	2.00	2.94	1.32	14.77	49.40	16.28

4	*Castanopsis* spp.	0.00	0.00	0.02	0.00	0.00	0.02	27.50	13.30
5	*Cedrus deodara*	3.12	1.41	0.29	0.32	0.21	5.35	54.40	20.49
6	*Pinus roxburghii*	1.87	1.87	0.93	1.12	0.59	6.39	44.28	21.29
7	*Pinus wallichiana*	5.00	4.29	2.67	3.31	1.81	17.08	61.82	24.06
8	*Quercus* spp.	61.21	59.58	15.44	12.43	9.67	158.33	56.09	16.60
9	*Rhododendron* spp.	109.0	98.93	21.84	8.23	1.45	239.45	26.13	8.86
10	*Schima wallichii*	5.00	6.95	2.13	0.97	0.17	15.23	32.10	14.24
11	*Tsuga* spp.	4.06	4.53	0.84	0.84	2.40	12.67	96.86	26.50
14	Other species	284.2	181.39	42.21	20.44	7.61	535.85	39.75	13.15
	Total	484.08	375.04	95.03	57.23	29.22	1040.60	49.02	15.84

More than three quarters of stems (76.67 %) in the High Mountains and High Himal forests are in the quality class III, termed here as cull trees, and followed by high-quality sound trees (15.13 %) in the quality class I. Only 8.21 % of stems are classified as sound trees i.e. quality class II (Figure 8).

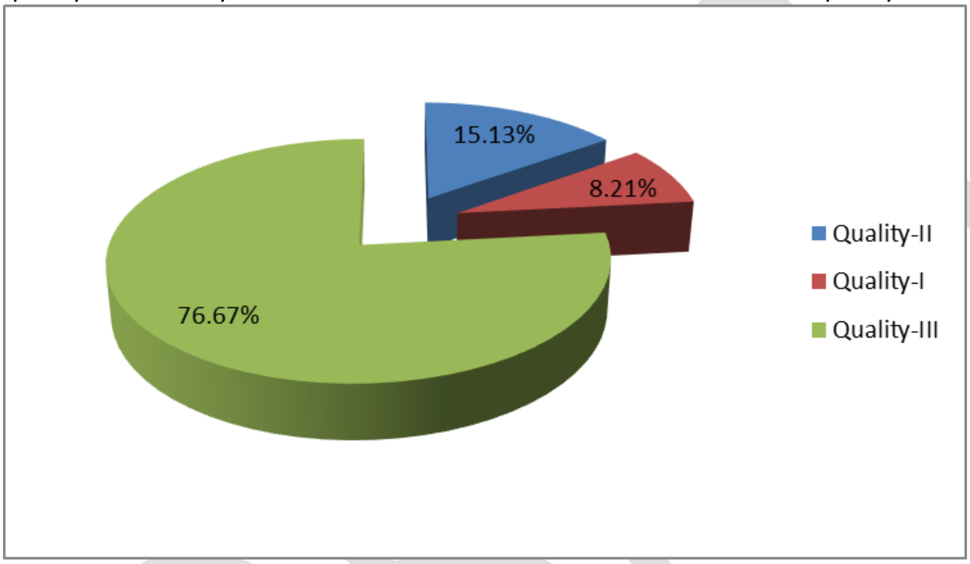

Figure 8: Number of stems by quality classes expressed as percentage

Rhododendron spp. are prominent in terms of number of stems (239/ha) followed by the *Quercus* spp. (158/ha). Both of these species groups have the highest number stems in quality class III (Table 7).

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

S.N.	Species Name	No of stems/ha by quality class Quality Class I	Quality Class II	Quality Class III	Total
1	*Abies* spp.	12.80	6.40	4.27	23.47
2	*Alnus nepalensis*	4.65	2.82	4.50	11.97
3	*Betula utilis*	3.38	2.94	8.45	14.77
4	*Castanopsis* spp.	0.02	0.00	0.00	0.02
5	*Cedrus deodara*	1.51	3.53	0.31	5.35
6	*Pinus roxburghii*	2.98	0.64	2.77	6.39
7	*Pinus wallichiana*	8.50	5.74	2.84	17.08
8	*Quercus* spp.	16.34	26.74	115.25	158.33
9	*Rhododendron* spp.	2.86	28.20	208.40	239.45
10	*Schima wallichii*	2.11	3.97	9.15	15.23
11	*Tsuga* spp.	5.58	2.54	4.55	12.67
12	Other species	24.66	73.89	437.30	535.85
	Total	**85.39**	**157.40**	**797.80**	**1040.60**

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 High Mountains and High Himal forests are 5946.6 and 2482.3 per ha, respectively. Like the larger stems, *Rhododendron* spp. has the largest number of seedlings and saplings (1256/ha), followed by *Quercus* spp. (827/ha) (Table 8).

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

S.N.	Species	Seedlings	Saplings	Total
1	*Abies spp.*	380.2	44.0	424.2
2	*Alnus nepalensis*	99.2	52.1	151.3
3	*Betula utilis*	29.4	20.0	49.3
4	*Castanopsis* spp.	0.0	0.0	0.0
5	*Cedrus deodara*	9.4	8.4	17.8
6	*Pinus roxburghii*	10.5	3.3	13.8
7	*Pinus wallichiana*	62.5	24.5	86.9
8	*Quercus* spp.	620.2	207.0	827.1
9	*Rhododendron* spp.	959.9	296.0	1255.9
10	*Schima wallichii*	81.1	39.8	120.9
11	*Tsuga* spp.	85.7	12.5	98.2
12	Other species	3608.6	1774.8	5383.3
	Total	5946.6	2482.3	8428.8

The total number of seedlings and saplings is highest in the moderately stocked forest (N=3389/ha) followed by poorly stocked forest (N=2731/ha) and well-stocked forest (N=3389/ha). Among the different development status, pole stage stand has the highest number of regeneration (N=3730/ha), followed by small saw timber stand (N=3285/ha). In terms of forest management regimes, community forests have the highest number of regeneration (4055/ha), followed by Government manage forests (1562/ha) (Table 9).

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

SN	**Canopy closure**	No of plots	Seedlings/ha	Saplings/ha	Total (No/ha)
1	Poorly stocked forest (0-39%)	142	1834.9	896.5	2731.5
2	Moderately stocked forest (40–69%)	296	2350.3	1039.1	3389.3
3	Well stocked forest (≥70%)	199	1761.3	546.7	2308.0
	Total	637	5946.6	2482.3	8428.8
	Development status				
1	Seedling and sapling stand (<12.5 cm DBH)	11	49.1	37.9	87.0
2	Pole timber stand (12.5–25.0 cm DBH)	172	2602.2	1128.0	3730.2
3	Small saw timber stand (25.0–50.0 cm DBH)	271	2402.5	882.2	3284.7
4	Large saw timber stand (>50.0 cm DBH)	183	892.7	434.2	1326.9
	Total	637	5946.6	2482.3	8428.8

	Management regime				
1	Private Forest	32	609.3	325.3	934.7
2	Government managed forests	183	1063.7	497.8	1561.6
3	Protected areas	32	94.3	32.9	127.2
4	Buffer zone forests	12	461.5	57.4	518.9
5	Buffer zone community forests	21	436.9	148.8	585.7
6	Conservation area	73	427.6	167.5	595.1
7	Community Forests	273	2814.8	1240.4	4055.2
8	Religious Forests	4	10.0	9.7	19.7
11	Public Land Forests	4	21.9	2.5	24.4
12	Other	3	6.6	0.0	6.6
	Total	**637**	**5946.6**	**2482.3**	**8428.8**

3.2.3 Basal area

The basal area of live stems (DBH >= 5 cm) in the High Mountains and High Himal forests is 31.99 m^2 per hectare. Dominant stems constitute the highest proportion of basal area 19.09 m^2 per hectare (59.69%), followed by co-dominant ones 7.39 m^2 per hectare (23.11%). The proportion of understory has the lowest basal area 0.18 m^2 per hectare (Table 10).

Table 10: Basal area per ha by crown class

Status of stem	**Crown class**	**Basal area m^2/ha**	**Percent**
Standing Live Trees	Dominant	19.09	59.69
	Co-dominant	7.39	23.11
	Intermediate	3.34	10.46
	Suppressed	0.35	1.10
	Understory	0.18	0.58
	Top Cut	1.62	5.06
Subtotal		**31.99**	
Standing Dead Trees	Dead Usable	1.40	
	Dead Unusable	0.16	
Subtotal		**1.56**	
Removed	Felled	1.04	
	Missing	0.69	
Extraction within 5 years		**1.73**	

Quercus spp. constitutes the largest proportion of basal area (23.46%), followed by *Rhododendron* spp. (13.97%) and *Abies* spp. (7.19%). In terms of stem size, the largest DBH class (>= 50 cm) occupies the highest basal area (12.61 m^2/ha) whereas the smallest DBH class (5-10 cm) occupies the lowest basal area (2.16 m^2/ha) (Table 11).

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

		DBH (cm) class and basal area (m^2/ha)1						
S.N.	**Species Name**	5-10	10-20	20-30	30-50	>50	Total	Percent
1	*Abies* spp.	0.02	0.13	0.20	0.50	1.45	**2.30**	7.19
2	*Alnus nepalensis*	0.01	0.06	0.13	0.30	0.45	**0.95**	2.96
3	*Betula utilis*	0.01	0.10	0.10	0.34	0.45	**0.99**	3.11
4	*Castanopsis* spp.	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00

5	*Cedrus deodara*	0.02	0.02	0.01	0.04	0.09	**0.18**	0.57
6	*Pinus roxburghii*	0.01	0.03	0.04	0.13	0.16	**0.38**	1.19
7	*Pinus wallichiana*	0.02	0.08	0.13	0.40	0.81	**1.45**	4.52
8	*Quercus* spp.	0.28	1.00	0.74	1.48	4.01	**7.50**	23.46
9	*Rhododendron* spp.	0.50	1.63	1.01	0.90	0.43	**4.47**	13.97
10	*Schima wallichii*	0.03	0.10	0.10	0.10	0.06	**0.40**	1.25
11	*Tsuga* spp.	0.02	0.07	0.04	0.11	1.48	**1.72**	5.36
12	Other species	1.24	2.96	1.97	2.27	3.21	**11.65**	36.43
	Total	**2.16**	**6.18**	**4.48**	**6.56**	**12.61**	**31.99**	

3.2.4 Stem volume

The total volume of live stems (DBH >= 5 cm) in the High Mountains and High Himal forests is 421.66 million m^3 (232.03 m^3/ha). Dominant stems constitute the highest proportion of stem volume (69.01 %), followed by co-dominant (18.46 %). The total volume of standing dead stems is 57.30 million m^3 (13.53 m^3/ha), of which nearly 90% percent is usable. A total of 17.52 million m^3 (9.64 m^3/ha) of stem volume is estimated to have been removed in the last five years (Table 12).

Table 12: Stem volume per ha by crown class

Status of stem	Crown class	Stem volume(m^3/ha)	Stem volume/ha (%)
Standing Live Trees	Dominant	160.13	69.01
	Co-dominant	42.83	18.46
	Intermediate	15.93	6.86
	Suppressed	1.59	0.69
	Understory	0.76	0.33
	Top Cut	10.78	4.65
Total		**232.03**	100.00
Standing Dead Trees	Dead Usable	11.84	
	Dead Unusable	1.69	
Total		**13.53**	
Stem removal (last five years)		**9.64**	

Rhododendron spp. constitutes largest stem volume (239.45 m^3/ha) in the High Mountains and High Himal forests, followed by *Quercus* spp. (158.33 m^3/ha). In terms of stem size, highest volume is occupied by the small size trees (5-10cm) and seems gradually decreasing with increasing DBH classes (Table 13).

Table 13: Stem volume per ha by species and DBH class

S.N.	Species Name	DBH (cm) class and stem volume (m^3/ha)					Total
		5-10	10-20	20-30	30-50	>50	
1	*Abies* spp.	5.62	6.95	3.98	4.14	2.79	23.47
2	*Alnus nepalensis*	2.19	3.44	2.69	2.47	1.19	11.97
3	*Betula utilis*	2.81	5.70	2.00	2.94	1.32	14.77
4	*Castanopsis spp.*	0.00	0.00	0.02	0.00	0.00	0.02
5	*Cedrus deodara*	3.12	1.41	0.29	0.32	0.21	5.35
6	*Pinus roxburghii*	1.87	1.87	0.93	1.12	0.59	6.39
7	*Pinus wallichiana*	5.00	4.29	2.67	3.31	1.81	17.08
8	*Quercus* spp.	61.21	59.58	15.44	12.43	9.67	158.33
9	*Rhododendron* spp.	109.00	98.93	21.84	8.23	1.45	239.45

10	*Schima wallichii*	5.00	6.95	2.13	0.97	0.17	15.23
11	*Tsuga* spp.	4.06	4.53	0.84	0.84	2.40	12.67
14	Other species	284.20	181.39	42.21	20.44	7.61	535.85
	Total	**484.08**	**375.04**	**95.03**	**57.23**	**29.22**	**1040.60**

In terms of volume, high-quality sound trees (quality I) holds the highest stem volume (121.16 m^3/ha), followed by cull trees (quality III) and sound trees (quality II) with 67.46 m^3/ha and 43.41 m^3/ha, respectively (Table 14).

Table 14: Stem volume per ha by species and quality class

S.N.	Species Name	Stem volume (m^3/ha) by stem quality			Total
		Quality-I	**Quality-II**	**Quality-III**	
1	*Abies* spp.	19.88	2.55	1.20	23.63
2	*Alnus nepalensis*	7.00	1.37	0.93	9.30
3	*Betula utilis*	2.89	2.02	1.98	6.89
4	*Castanopsis* spp.	0.01	0.00	0.00	0.01
5	*Cedrus deodara*	1.27	0.20	0.00	1.47
6	*Pinus roxburghii*	3.57	0.15	0.21	3.93
7	*Pinus wallichiana*	13.04	1.16	0.24	14.44
8	*Quercus* spp.	32.61	14.19	16.65	63.46
9	*Rhododendron* spp.	1.14	4.83	14.81	20.77
10	*Schima wallichii*	1.09	0.70	0.74	2.53
11	*Tsuga* spp.	14.64	0.38	1.01	16.03
12	Other species	24.02	15.85	29.69	69.56
	Total	**121.16**	**43.41**	**67.46**	**232.03**

The total stem volume and volume of stems up to 10 cm top diameter and up to 20 cm top diameter without bark are 190.73, 173.63 and 148.56 m^3 per hectare respectively (Table 15).

Table 15: Stem volume without bark per ha by species

S.N.	Species	Stem volume without bark (m^3/ha)		
		Total Stem	**Up to 10 cm top diameter**	**Up to 20 cm top diameter**
1	*Abies* spp.	20.55	20.24	18.69
2	*Alnus nepalensis*	8.21	8.03	7.14
3	*Betula utilis*	5.47	5.14	4.55
4	*Castanopsis* spp.	0.01	0.01	0.00
5	*Cedrus deodara*	1.18	1.09	1.00
6	*Pinus roxburghii*	3.02	2.92	2.69
7	*Pinus wallichiana*	12.89	12.41	11.56
8	*Quercus* spp.	55.35	53.47	47.66
9	*Rhododendron* spp.	15.45	11.34	6.66
10	*Schima wallichii*	1.49	1.29	0.89
11	*Tsuga* spp.	13.36	13.13	13.10
12	Other species	53.75	44.56	34.59
	Total	**190.73**	**173.63**	**148.56**

Stem volume without bark and volume up to 10 cm and 20 cm top diameter of different species by stem quality classes is presented in Table 16.

Table 16: Stem volume without bark per ha by species and quality class

S. N.	Species Name	Stem quality class and volume without bark (m³/ha)								
		Quality-I			Quality-II			Quality-III		
		Total stem	Up to 10 cm top dia.	Up to 20 cm top dia.	Total stem	Up to 10 cm top dia.	Up to 20 cm top dia.	Total stem	Up to 10 cm top dia.	Up to 20 cm top dia.
1	*Abies* spp.	17.39	17.20	16.11	2.15	2.08	1.74	1.01	0.96	0.84
2	*Alnus nepalensis*	6.19	6.15	5.70	1.20	1.14	0.87	0.82	0.74	0.58
3	*Betula utilis*	2.31	2.23	2.04	1.62	1.55	1.43	1.54	1.36	1.09
4	*Castanopsis* spp.	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	*Cedrus deodara*	1.03	1.01	0.96	0.15	0.09	0.04	0.00	0.00	0.00
6	*Pinus roxburghii*	2.79	2.74	2.57	0.10	0.09	0.05	0.13	0.10	0.07
7	*Pinus wallichiana*	11.71	11.37	10.80	0.99	0.89	0.68	0.19	0.15	0.09
8	*Quercus* spp.	28.89	28.65	27.54	12.34	11.96	10.49	14.12	12.86	9.64
9	*Rhododendron* spp.	0.89	0.83	0.69	3.69	3.15	2.20	10.88	7.35	3.77
10	*Schima wallichii*	0.72	0.70	0.54	0.40	0.34	0.19	0.37	0.25	0.16
11	*Tsuga* spp.	12.26	12.15	12.25	0.30	0.25	0.19	0.81	0.73	0.66
12	Other species	19.63	19.06	18.06	12.21	10.60	7.82	21.91	14.89	8.72
	Total	**103.81**	**102.09**	**97.25**	**35.14**	**32.15**	**25.70**	**51.78**	**39.39**	**25.61**

dia. = diameter

3.2.5 Biomass

The High Mountains and High Himal forests contain a total of 746.54 million tons of air-dry biomass (410.80 t/ha), equivalent to 678.68 million tons of oven-dry biomass (373.46 t/ha). 80 % of the total biomass is represented by the aboveground components, i.e. live stems (88.19 %), dead stems (3.59 %), and deadwood (8.21 %). Among the three components of live trees, stem and branch share over 53.77 % and 37.58 % of the total biomass respectively (Table 17).

Table 17: Biomass in the High Mountains and High Himal forests (DBH>=5 cm)

Aboveground	Tree components	Air-dry biomass (T/ha)
1 Live stems	Stem	155.88
	Branch	108.94
	Foliage	25.03
	Sub-total (a)	**289.85**
2 Dead stems	Stem	8.42
	Branch	3.37
	Sub-total (b)	**11.80**

Dead wood (c)	**26.99**
Total Above Ground Biomass (a+b+c)	**328.64**
Below ground biomass (BGB) (@ 25% of total AGB)	**82.16**
Total air-dry biomass (AGB + BGB)	**410.80**
Total oven-dry biomass (@ 90.90 % of the total air dry biomass)	**373.46**

In terms of species, *Quercus* spp. contributes more than 50 t/ha *followed by Rhododendron and Abies* spp. (Figure 9).

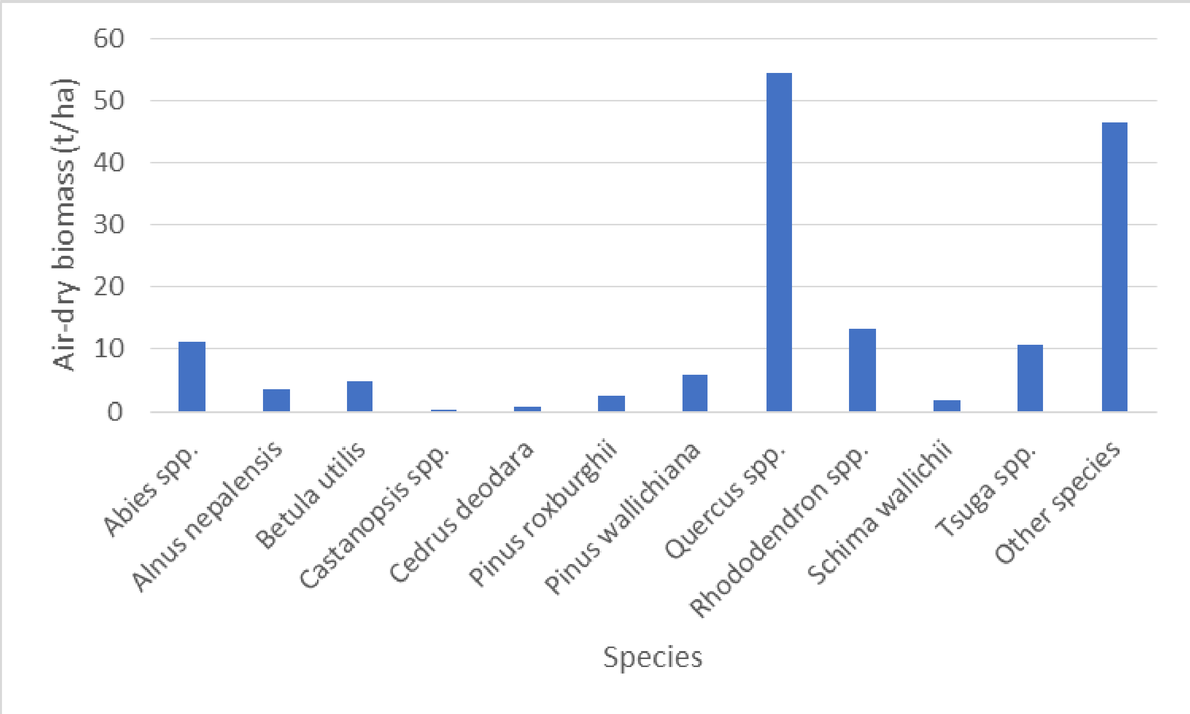

Figure 9: Aboveground biomass (air-dry) of live stems (DBH>=5cm) by species (t/ha)

3.2.6 Carbon stock

Total carbon stock in the three major carbon pools of High Mountains and High Himal forests is 539.23 million t C. The average carbon stock in forest is 296.72 t/ha. Out of all, tree component contains nearly 60 % while the litter and debris component represents less than 1 % (Table 18).

Table 18: Forest carbon stock in different pools

Carbon pool	Carbon stock (t/ha)
Tree component (=>5cm dbh)	175.53
Litter and debris	0.3
Soil organic carbon	120.89 To be updated later
Total carbon stock	**296.72** To be updated later

3.2.7 Forest disturbances

A range of disturbances occurs in the High Mountains and High Himal forests. Livestock grazing, tree cutting, forest fire, and sapling/pole cutting are the most prevalent disturbances (Figure 10).

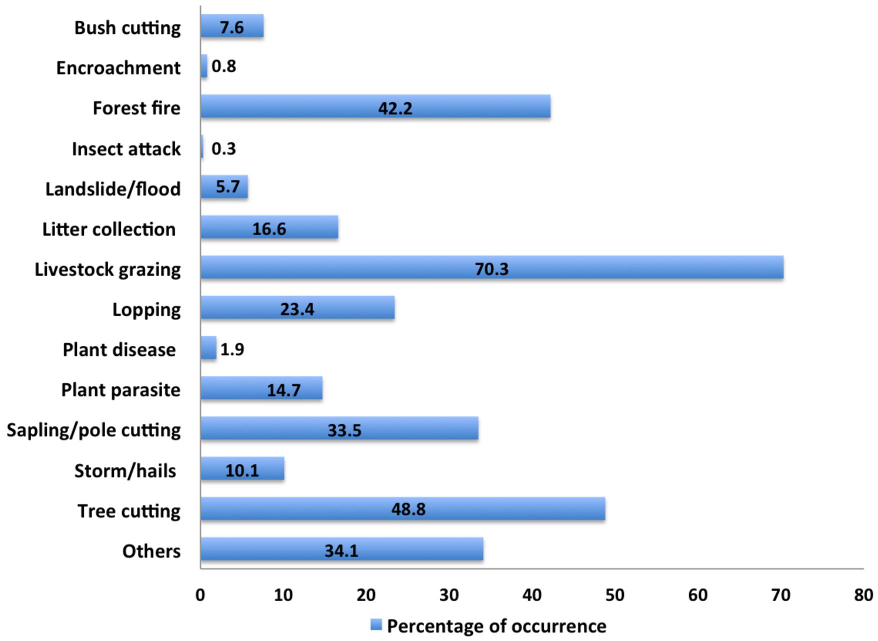

Figure 10: Occurrence of forest disturbances

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).

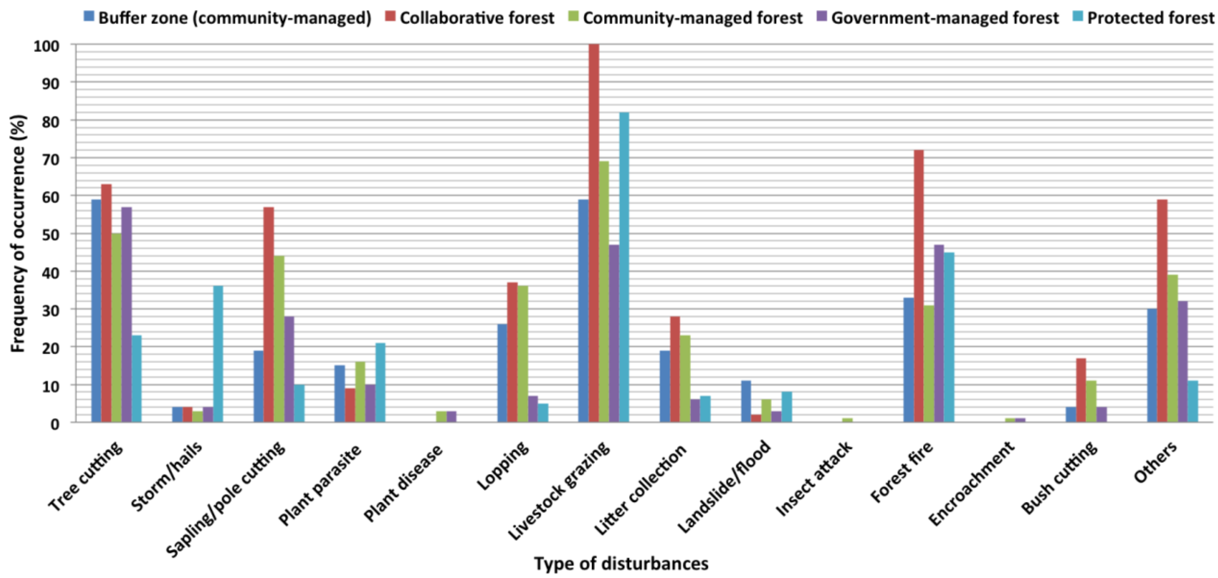

Figure 11: Occurrence of forest disturbances by forest management regimes

3.2.8 Accuracy assessment

Different metrics for accuracy evaluation of derived forest inventory variables are presented in Table 19.

Table 19: Accuracy of results of some main variables

Description	Number of stems	Basal area (m2/ha)	Stem Volume (m3/ha)	Air-dry biomass (t/ha)	Carbon stock (t/ha)	SVWP up to 10 cm	SVWB up to 20 cm

	(>=5 cm dia)/ha					**top dia.**	**top dia.**
Standard Error	48.81	1.19	11.15	0.22	0.09	9.82	9.75
Mean	1040.60	31.99	232.03	5.69	2.43	173.63	148.56
% Error of Mean	4.69	3.71	4.81	3.85	3.85	5.65	6.56
% of Error of Mean at 95% CI	9.19	7.28	9.42	7.54	7.54	11.08	12.86
Lower limit at 95% CI	944.93	29.66	210.17	5.26	2.25	154.39	129.46
Upper limit at 95% CI	1136.26	34.32	253.89	6.12	2.61	192.87	167.66

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

A separate accuracy assessment of the forest cover maps of High Mountains and High Himal was not done as they were derived as a spatial subset of the national land cover map.

References

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).

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.

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

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.

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

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.

Matthews, S., Shivakoti, G.P. and Chhetri, N. 2000. Population Forces and Environmental Change: Observations from Western Chitwan, Nepal. Society and Natural Resources, 13: 763-775.

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.

Pariyar, D. 2008. Country Pasture/Forage Resource Profiles. FAO Country Profile: Nepal. Kathmandu, Nepal.

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.

Upreti, B.N. 1999. An overview of the stratigraphy and tectonics of the Nepal Himalaya. Journal of Asian Earth Sciences 17: 577– 606.

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

Annex-1: Summary of diameter-height model

SN	Species	Model name	a	b	SE (a)	SE(b)
1	*Abies* species	Abies	3.0936590	0.1585649	0.18	0.01
2	*Acer* species	Acer	2.2075531	0.2059752	0.26	0.01
3	*Aesculus indica*	Aesculus	3.534788	0.169819	0.43	0.01
4	*Alnus nepalensis*	Alnus	1.9871143	0.1751616	0.20	0.01
5	*Betula utilis*	Betula	2.1839347	0.2093686	0.36	0.01
6	*Castanopsis* species	Castanopsis	2.7220615	0.2033489	0.63	0.03
7	*Cedrus deodara*	Cedrus	3.500603	0.151178	0.30	0.01
8	*Daphniphyllum himalense*	Daphniphyllum	2.9538767	0.1789782	0.60	0.02
9	*Dodecadenia grandiflora*	Dodecadenia	1.9340550	0.2402255	0.38	0.02
10	*Eurya acuminata*	Eurya	1.9847139	0.2408835	0.28	0.02
11	*Ilex dipyrena*	Ilex	4.380952	0.194190	1.09	0.03
12	*Lyonia* species	Lyonia	1.7371142	0.2649745	0.14	0.01
13	*Myrica esculenta*	Myrica	1.7776420	0.2620742	0.30	0.01
14	*Persea duthiei*	Persea	1.9801077	0.2362173	0.31	0.01
15	*Picea smithiana*	Picea	2.8771830	0.1463163	0.31	0.01
16	*Pinus* species	Pinus	35.78432	23.85904	2.14	2.43
17	*Prunus napaulensis*	Prunus	2.4352073	0.1968111	0.49	0.02
18	*Quercus* species	Quercus	3.468618	0.180490	0.11	0.01
19	*Rhododendron* species	Rhododendron	1.7981283	0.2808672	0.10	0.01
20	*Schima wallichii*	Schima	2.0578817	0.1988211	0.31	0.01
21	*Symplocos ramosissima*	Symplocos	2.0247138	0.2083224	0.21	0.01
22	*Tsuga dumosa*	Tsuga	3.492533	0.155424	0.36	0.01
23	Others	Misc	2.1580693	0.2215671	0.13	0.01

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*.