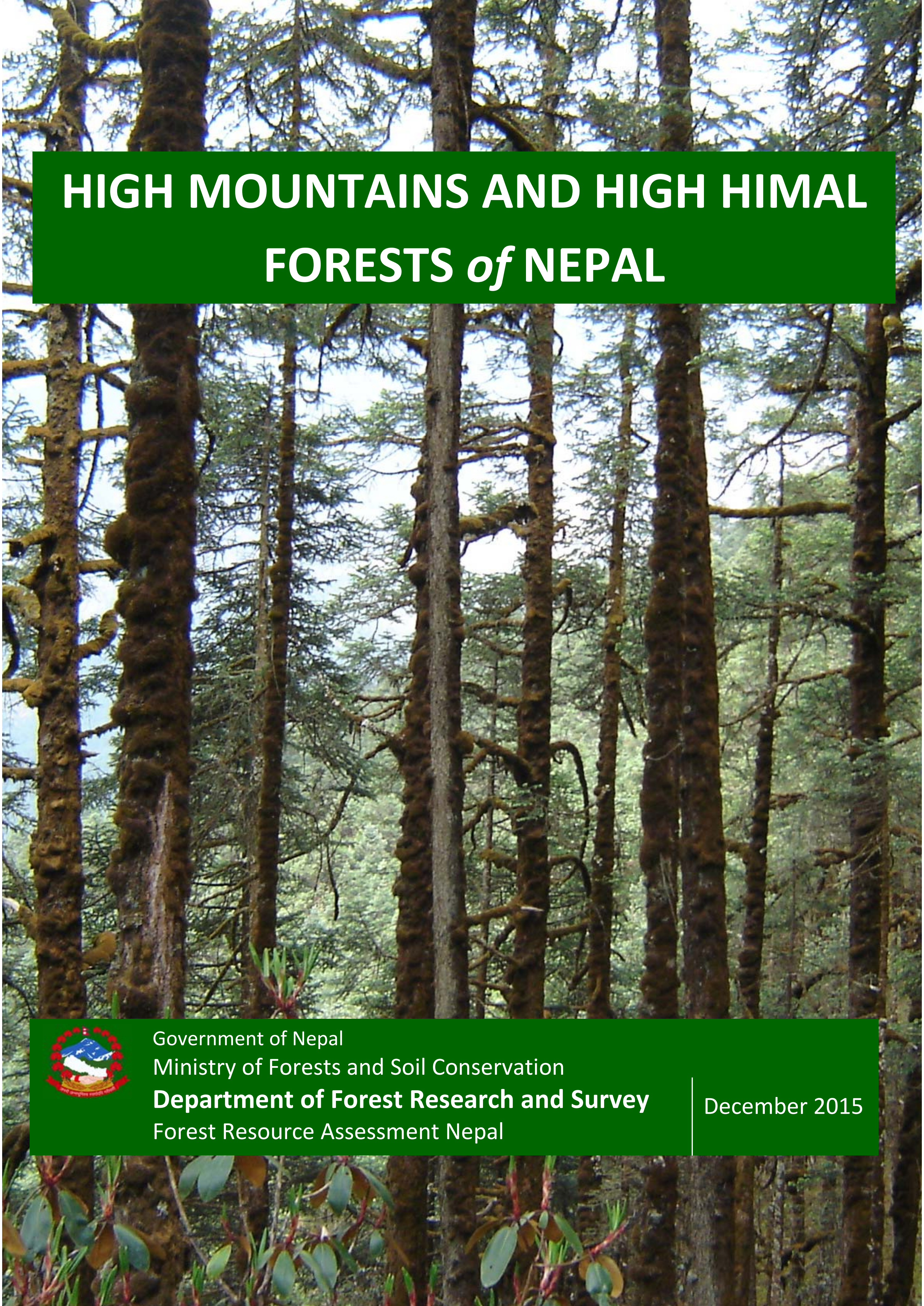
HIGH MOUNTAINS AND HIGH HIMAL FORESTS *of* NEPAL



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Ministry of Forests and Soil Conservation
Department of Forest Research and Survey
Forest Resource Assessment Nepal

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HIGH MOUNTAINS AND HIGH HIMAL FORESTS OF NEPAL

FOREST RESOURCE ASSESSMENT NEPAL

DEPARTMENT OF FOREST RESEARCH AND SURVEY

MINISTRY OF FORESTS AND SOIL CONSERVATION

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Cover photograph

Foreword

The Government of Nepal, with support from the Government of Finland, implemented the Forest Resource Assessment Nepal (FRA Nepal) project from 2010 to 2014 with an aim to generate forest resource information for supporting policy-making, strategic planning and international reporting.

All five physiographic regions of the country were covered in this assessment. This report presents the results of the forest resource assessment of the High Mountains and High Himal physiographic regions of Nepal. The report gives a wide range of information including forest cover, growing stock, biomass and forest carbon. Results of the study show that the forest areas of the High Mountains and High Himal physiographic regions have increased since the last assessment period.

I appreciate the efforts of all those involved in planning, field inventory, data analysis, mapping, report writing and other supportive work related to FRA Nepal project. I express my sincere thanks to the Government of Finland for providing technical and financial support to undertake this important project.

I believe that the results of this study will be useful to policy-makers, planners, managers, academicians, students and all those with an interest in planning and management of forest resources of the High Mountains and High Himal physiographic regions of Nepal.

Uday Chandra Thakur

Secretary

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Prakash Mathema

Director General

Department of Forest Research and Survey

ACRONYMS AND ABBREVIATIONS

BD	Bulk Density
BRDF	Bidirectional Reflectance Distribution Function
BZ	Buffer Zone
CART	Classification and Regression Trees
CBS	Central Bureau of Statistics
CCA	Canonical Corresponding Analysis
CCSP	Concentric Circular Sample Plot
CF	Community Forest
CFUG	Community Forest User Group
DBH	Diameter at Breast Height (1.3 m)
DCA	Detrended Correspondence Analysis
DEM	Digital Elevation Model
DFRS	Department of Forest Research and Survey
DHM	Department of Hydrology and Meteorology
DoF	Department of Forests
DoS	Department of Survey
FAO	Food and Agriculture Organization of the United Nations
FF	Fine Fraction
FRA	Forest Resource Assessment
FRS	Forest Resources Survey
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
GoN	Government of Nepal
ha	Hectare
HH	High Himal
HM	High Mountains
IPCC	Intergovernmental Panel on Climate Change
LMH	Lower Mixed Hardwood
LRMP	Land Resources Mapping Project
m^3/ha	Cubic metre per hectare
METLA	Finnish Forest Research Institute
MFSC	Ministry of Forests and Soil Conservation
MPFS	Master Plan for Forestry Sector
MSS	Multi-Spectral Scanner
NDVI	Normalised Difference Vegetation Index
NFI	National Forest Inventory
NTFP	Non-timber Forest Product
OC	Organic Carbon

OL	Other Land
OWL	Other Wooded Land
PA	Protected Area
PSP	Permanent Sample Plot
REDD	Reducing Emissions from Deforestation and Forest Degradation
RMSE	Root Mean Square Error
SD	Standard Deviation
SE	Standard Error
SOC	Soil Organic Carbon
t/ha	Tonne per hectare
TMH	Terai Mixed Hardwood
UMH	Upper Mixed Hardwood

GLOSSARY

Above-ground biomass	Above-ground biomass refers to the biomass of trees and saplings (≥5 cm DBH) above the soil. It includes dead wood but not stumps.
Below-ground biomass	The biomass of trees and saplings (≥5 cm DBH) contained within live roots and stumps.
Biomass	The biological material derived from living or recently living organisms. It includes both the above-ground and below-ground biomass of trees and saplings.
Bulk density	Soil mass per unit volume, expressed in g/cm^3.
Carbon pool	Carbon content in above-ground and below-ground biomass, and soil.
Climber	Any plant which grows by trailing or climbing stems or runners.
Co-dominant tree	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 does not meet, and cannot be expected to meet regional merchantability standards (Quality-3).
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 tree	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.
Frequency	The rate of occurrence of a species within a unit area.
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 (Quality-1).
Intermediate tree	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 bio-physical material covering the surface of the earth.
Land use	The arrangements, activities and inputs people undertake on an area with a certain land-cover type to produce, change or maintain it.
Litter	Dead plant materials such as leaves, bark, needles, and twigs that have fallen to the ground.

Lower Mixed Hardwood (LMH)	Generally refers to Mixed species found between 1,000 m to 2,000 m.
Non-reachability	Plot is regarded as non-reachable if the slope within the plot is more than 45 degrees (100%).
NTFPs	Non-Timber Forest Products encompasses all biological materials other than timber, which are extracted from forests for human use.
Other Land	All land that is not classified as Forest or Other Wooded Land.
Other Wooded Land (OWL)	The 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%; includes area of shrubs and bushes where no trees are present.
Protected Area (PA)	It includes Core Area (National Parks, Wildlife Reserve, Conservation Area and Hunting Reserve) and Buffer Zone.
Shrub	An area occupied by woody perennial plants, generally 0.5–5.0 m at maturity, and often without definite stems or crowns (Quality-2).
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 tree	A tree with a crown that is smaller 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.
Terai Mixed Hardwood (TMH)	A low altitude, broadleaf forest in which no species contributes 60% of the total basal area. In some situation, this forest type is edaphic but it can also result from selective removal of *Shorea robusta* trees.
Upper Mixed Hardwood (UMH)	Generally refers to mixed hardwood species in the high hills above 2,000 m.
Understory	A tree with a crown that is below the level of the general canopy and receives little or no direct sunlight though it does not show signs of suppressed or retarded growth.
Wall-to-wall mapping	Mapping that covers an entire area.

Main Results

Land Cover in High Mountains and High Himal

1. Out of the combined total area of High Mountains and High Himal (6,548,766 ha), Other Land covers the greatest proportion (62.19%; 4,072,426 ha), followed by Forest (29.36%; 1,922,909 ha) and Other Wooded Land (8.45%; 553,431 ha). Forest and OWL together cover 37.81% (2,476,340 ha) in this region.
2. Out of the total 1,922,909 ha of forest cover in High Mountains and High Himal, 69.96% was outside Protected Areas (PAs) and 30.04% inside PAs (23.88% in the Core Area and 6.16% in the Buffer Zone).

Growing Stock

3. In High Mountains and High Himal the total number of trees with Diameter at Breast Height (DBH) ≥5 cm is 2,116.44 million. Out of this, 1,895.32 million (985.65/ha) is on Forest, 64.84 million (133.86/ha) on OWL and 156.28 million (130.56/ha) on Other Land.
4. Regeneration in High Mountains and High Himal forests is found to be an average of 2,399 seedlings (height <1.3 m) and 831 saplings (height ≥1.3 m and DBH <5 cm) per hectare.
5. In High Mountains and High Himal, the total stem volume with DBH ≥5 cm is 467.96 million m^3 of which 446.92 million m^3 (232.42 m^3/ha) is on Forest, 3.93 million m^3 (8.11 m^3/ha) on OWL and 17.10 million m^3 (14.29 m^3/ha) on Other Land.
6. The total air-dried biomass of live trees with DBH ≥5 cm is 561.56 million tonnes in High Mountains and High Himal. Out of the total biomass, 538.12 million tonnes (279.85 t/ha) is on Forest, 5.84 million tonnes (12.05 t/ha) on OWL and 17.61 million tonnes (14.71 t/ha) on Other Land.

Carbon stock

7. The total carbon stock in High Mountains and High Himal forests was estimated to be 523.81 million tonnes (272.40 t/ha).

Biodiversity and Disturbance

8. Altogether 275 tree species were recorded in the measured plots.
9. A total of 755 species of flora and derivatives of 78 species of fauna were reported to be used as non-timber forest products (NTFPs).
10. Out of the fourteen categories of natural and anthropogenic forest disturbances observed, grazing and tree cutting were the most common.

प्रमुख नतिजाहरुः

वन क्षेत्र

१. उच्चपहाडी तथा उच्च हिमालीभागको कुल क्षेत्रफल ६,५४८,७६६ हेक्टरमध्ये वनक्षेत्रले १,९२२,९०९ हेक्टर (२९.३६%), अन्य काष्ठ तथा बुट्यानक्षेत्र (Other Wooded Land) ले ५५३,४३१ हेक्टर (८.४५%) र अन्य क्षेत्र (Other Land) ले ४,०७२,४२६ हेक्टर (६२.१९%) ओगटेको छ । यसरी वनक्षेत्र र काष्ठ तथा बुट्यानक्षेत्र दुबैले गरी २,४७६,३४० हेक्टर (३७.८१%) क्षेत्रफल ओगटेको छ ।

२. कुल वनक्षेत्र मध्ये संरक्षितक्षेत्र भन्दा बाहिर ६९.९६% र संरक्षितक्षेत्र भित्र ३०.०४% (भित्रि भाग - core area मा २३.८८% र मध्यवर्ती क्षेत्रमा ६.१६%) रहेको पाइयो ।

रुखको मौज्दात

३. उच्चपहाडी तथा उच्च हिमालीभागमा कुल रुख (जमीनबाट १.३ मिटरको उचाईमा कम्तिमा ५ से.मि. व्यास भएका) को संख्या २ अर्व ११ करोड ६४ लाख रहेको पाइयो । यसमध्ये वनमा १ अर्ब ८९ करोड ५३ लाख (९८५.६५ प्रति हेक्टर), अन्य काष्ठ तथा बुट्यान (OWL) क्षेत्रमा ६ करोड ४८ लाख (१३३.८६ प्रति हेक्टर) र अन्य क्षेत्र (Other Land) मा १५ करोड ६३ लाख (१३०.५६ प्रति हेक्टर) पाइयो ।

४. पुनरुत्पादनको अवस्था हेर्दा यस क्षेत्रमा औसतमा प्रति हेक्टर विरुवा (उचाई १.३ मि. भन्दा कम) को संख्या २,३९९ र लाथ्रा (उचाई १.३ मि. वा सो भन्दा बढी र ब्यास ५ से.मि. भन्दा कम) को संख्या ८३१ रहेको पाइयो ।

५. उच्चपहाडी तथा उच्च हिमालीक्षेत्रमा ५ से.मि. र सो भन्दा बढि व्यास (१.३ मि. उचाईमा) भएका जीवित रुखहरूको कुल काण्ड आयतन (stem volume) करिब ४६ करोड ८० लाख घन मिटर रहेको अनुमान गरिएको छ । कुल आयतनमध्ये वनक्षेत्रमा ४४ करोड ६९ लाख घन मिटर (२३२.४२ घन मिटर प्रति हेक्टर), अन्य काष्ठ तथा बुट्यान क्षेत्रमा करिब ३९ लाख घन मिटर (८.११ घन मिटर प्रति हेक्टर) र अन्य क्षेत्रमा करिब १ करोड ७१ लाख घन मिटर (१४.२९ घन मिटर प्रति हेक्टर) पाइयो ।

६. उच्चपहाडी तथा उच्च हिमालीक्षेत्रमा जीवित रुखको कुल जैविक पिण्ड (air-dried biomass) करिब ५६ करोड १६ लाख टन पाइयो । कुल जैविक पिण्ड मध्ये वनक्षेत्रमा करिब ५३ करोड ८१ लाख टन (२७९.८५ टन प्रति हेक्टर), अन्य काष्ठ तथा बुट्यान क्षेत्रमा करिब ५८ लाख टन (१२.०५ टन प्रति हेक्टर) र अन्य क्षेत्रमा करिब १ करोड ७६ लाख टन (१४.७१ टन प्रति हेक्टर) रहेको पाइयो ।

कार्वन संचिति

७. उच्चपहाडी तथा उच्च हिमाली वनक्षेत्रमा कुल कार्बन संचिति करिब ५२ करोड ३८ लाख टन (२७२.४० टन प्रति हेक्टर) रहेको अनुमान गरियो ।

जैविक विविधता र मानवीय एवं प्राकृतिक क्रियाकलापहरु

८. उच्चपहाडी तथा उच्च हिमाली वनक्षेत्रका मापन गरिएका प्लटहरुमा २७५ वटा रुख प्रजातिहरु पाइयो ।

९. गैह्रकाष्ठ वन पैदावारको रुपमा ७५५ वटा वनस्पति प्रजाति र ७८ वटा जीवजन्तु प्रजातिहरुका अवयवहरु प्रयोगमा आइरहेको पाइयो ।

१०. यस क्षेत्रमा जम्मा १४ प्रकारका प्राकृतिक तथा मानवीय प्रभावहरु पाइयो जसमध्ये चरिचरन र रुखकटान मुख्य रहेको पाइयो ।

EXECUTIVE SUMMARY

High Mountains (HM) region covers 3,009,210 ha i.e. 20.4% of the total land area of the country. This region has a cold climate and receives heavy to moderate snowfall in winter. Similarly, High Himal (HH) region occupies 3,533,947 ha i.e. 23.9% of the total land area of the country. High Himal falls largely within the alpine and arctic climatic regimes, so there are active glacier systems in high altitude catchments. Data of those two regions was combined for analysis and reporting due to the following reasons: (i) number of sample plots were not sufficient in each physiographic region (HM and HH), (ii) forest types and species composition of both the regions are similar, and (iii) the number of measured sample plots in both the physiographic regions are in proportion to their respective total forest area.

Methodology

In both High Mountains and High Himal regions, forest cover was mapped by adopting a hybrid approach, which used automated image classification supported by extensive visual interpretation. Images were classified by applying segmentation and automated object-based image analysis method.

In both regions, 24,554 sample plots in 4,096 clusters were visually interpreted by using standardised procedures. A total of 4,096 clusters were laid out systematically at the nodes of 4 km x 4 km square grids across the entire High Mountains and High Himal regions and were divided into two strata. Clusters in the first stratum (forest stratum) had at least one plot (out of six) with Forest; clusters in the second stratum (zero-forest) had no Forest plot out of six. A total of 188 clusters from the first stratum and 52 clusters from the second stratum were selected. In the first stratum, there were 882 plots in Forest, 99 plots in OWL, and 147 plots in OL. Similarly, in the second stratum, there were 72 plots in OWL and 240 in OL.

During field measurement, only 624 sample plots out of 1,440 were measured. The remaining 816 sample plots could not be inventoried because of non-reachability. Out of the 624 measured sample plots, 468 were in Forest, 26 in OWL and 130 in OL. In each cluster, measurements of tree characteristics, soil sampling, biodiversity and social surveys were carried out. Each cluster had six plots and each plot comprised of four concentric circles of different radii, each of which was used to measure trees with a different DBH range.

Land Cover

Out of the total area of 6,548,766 ha in High Mountains and High Himal region, Other Land covered the greatest proportion (62.19%; 4,072,426 ha), followed by Forest (29.36%; 1,922,909 ha) and Other

Wooded Land (8.45%; 553,431 ha). Forest and OWL together cover 37.81%; (2,476,340 ha). Out of the total 1,922,909 ha of Forest cover in High Mountains and High Himal, 69.96% falls outside PAs and 30.04% inside PAs. Out of 30.04% forested areas inside PAs, 23.88% is in Core Area and 6.16% area is in Buffer Zones. Potential production forest with the criterion of forest outside Protected Areas and a maximum slope less than 35% was found to be 255,038 ha (i.e. 13.26% of total forest area).

In High Mountains region, 57.58% (1,732,759 ha) was covered by Forest and 10.97% (330,197 ha) was OWL. Out of the total forest area, 73.08% (1,266,229 ha.) falls outside PAs and 26.92% (466,530 ha) inside PAs. Similarly, in High Himal region, forests cover only 5.37% (190,150 ha) and OWL covers 6.31% (223,234 ha). Out of the total forested area, 41.59% (79,080 ha) falls outside PAs and 58.41% (111,070 ha) inside PAs. The results of forest cover mapping in the both HM and HH were compared with 317 independent ground samples from the national forest inventory. The land cover classes (Forest, OWL including shrub and Other Land) observed in the field were compared with the classified land cover classes. An overall accuracy of 66.56%, a Cohen's *kappa* (κ) of 0.68, and a *kappa* standard error of 0.04 were attained.

Forest Inventory

The High Mountains and High Himal forests had an average of 2,399 seedlings and 831 saplings per hectare. The total number of stems with DBH ≥5 cm was 2,116.44 million. Out of the total number of stems, 1,895.32 million (985.65 stems/ha) were in Forest, 64.84 million (133.86 stems/ha) in OWL and 156.28 million (130.56 stems/ha) in Other Land. *Rhododendron* spp. was the dominant species (234.45 stems/ha), followed by *Quercus* spp. (149.46 stems/ha). The average number of stems per hectare comprised 123 high-quality sound trees (quality class 1), 215 sound trees (quality class 2), and 648 cull trees (quality class 3).

The basal area of stems (≥5 cm DBH) was 30.54 m^2/ha in Forest, 1.68 m^2/ha in OWL, and 2.51 m^2/ha in Other Land. The total stem volume was 467.96 million m^3 out of which 446.92 million m^3 (232.42 m^3/ha) was in Forest, 3.93 million m^3 (8.11 m^3/ha) in OWL and 17.10 million m^3 (14.29 m^3/ha) in Other Land. The standard error of the mean stem volume of Forest was 6.76%. The total stem volume of standing dead trees and dead wood was 6.99 m^3/ha and 18.32 m^3/ha, respectively. The total air-dried biomass of live trees (≥5 cm DBH) was 561.56 million tonnes. Of the total biomass, 538.12 million tonnes (279.85 t/ha) was in Forest, 5.84 million tonnes (12.05 t/ha) in OWL and 17.61 million tonnes (14.71 t/ha) in Other Land.

Forest Carbon

The total carbon stock in combined HM and HH forests was estimated to be 523.81 million tonnes (272.40 t/ha). Out of the total carbon pool in the forest, tree component contributed 57.61%; soil 41.86% and litter and debris 0.53%. Soil Organic Carbon was the highest (128.06 t/ha) in Far-Western Development Region, followed by Eastern Development Region (127.91 t/ha).

Biodiversity

Altogether 275 tree species belonging to 157 genera and 79 families were recorded in the sample plots in the physiographic regions. According to social surveys, 755 different species of flora (i.e. 227 tree species, 159 shrub species, 277 herb species, 56 climber species and 36 ferns and fern-allies) were used as NTFPs. Derivatives of 78 animal species were reported to be used in HM and HH sampling sites.

Forest Disturbances

Fourteen categories of natural and anthropogenic forest disturbances were observed. Out of the total instances of disturbance (1,103) recorded, 15% had no impact, 37% had minor impact, 34% had medium impact and 14% had strong impact. Grazing and tree cutting were the most commonly reported disturbances in the forests.

सारांश

नेपालको उच्च पहाडी भौगोलिक क्षेत्रले देशको कुल भ-ूभागको करिब २०.४% क्षेत्रफल ओगटेको छ । त्यसैगरी, उच्च हिमाली क्षेत्रले देशको कुल भू-भागको करिब २३.९% (३,५३३,९४७ हेक्टर) क्षेत्रफल ओगटेको छ ।

उच्चपहाडी तथा उच्च हिमालीक्षेत्रको भू-आवरण (Land cover) लाई मुख्यतः वनक्षेत्र (Forest), अन्य काष्ठ तथा बुट्यान क्षेत्र (Other Wooded Land) र अन्य क्षेत्र (Other Land) गरी तीन भागमा वर्गिकरण गरी नक्सांकन गरिएको थियो । यस क्रममा विभिन्न गुणस्तरका भू-उपग्रह चित्रहरु (जस्तै RapidEye, Landsat) र भू-उपयोग तथा आकृति नक्साहरु (जस्तै LRMP map तथा topographic map) को प्रयोग गरिएको थियो भने वर्गिकरण तथा नक्सांकन कार्यको गुणस्तरीयता र विश्वसनीयता कायम गर्न फिल्ड प्रमाणीकरण (Field verification) को अतिरिक्त Google Earth चित्रसंग समेत तुलनात्मक अध्ययन गरिएको थियो ।

वनस्रोत सर्वेक्षणको लागि नियमित नमुना सर्वेक्षण पद्यति (systematic sampling design) अनुसार पहिलो चरणमा उच्चपहाडी तथा उच्चहिमाली क्षेत्रभरि ४ कि.मि. को वर्गाकार ग्रिड बनाई ४,०९६ ठाँउ (cluster) मा जम्मा २४,५५४ प्लटहरु राखी अध्ययन गरिएको थियो । सर्वेक्षणको दोस्रो चरणमा २४० ठाँउका १,४४० नमुना प्लटहरु छनौट गरिएको थियो । जसमध्ये ६२४ (वन: ४६८, वुट्यान: २६ र अन्य क्षेत्र: १३०) प्लटहरु मात्र फिल्डमा मापन गर्न सम्भव भएको थियो । प्लटको केन्द्रबाट ४, ८, १५ र २० मिटरका वृत्तीय घेराहरु बनाएर रुखको आकार अनुसार नाप पैमाइस गरिएको थियो । यसको अतिरिक्त सोहि नमुना प्लटभित्र पर्ने गरी बुटयान प्रजाति र गैरकाष्ठ प्रजातिहरुको मापन र प्लटको चारवटा बाहिरी कुनाबाट माटोको नमुना संकलन समेत गरिएको थियो ।

भू-उपयोग नक्सांकनको आधारमा उच्चपहाडी तथा उच्च हिमालीक्षेत्रको करिब २९.३६% भू-भाग वन क्षेत्रले ओगटेको देखिन्छ भने अन्य काष्ठ तथा बुटयान क्षेत्र र अन्य क्षेत्र क्रमशः करिब ८.४५% र ६२.१९% भू-भागमा बिस्तारित छ । सर्वेक्षणबाट मध्यवर्ती क्षेत्रमा करिब ६.१६ % र भित्री क्षेत्रमा २३.८८ % गरी उच्चपहाडी तथा उच्च हिमालीक्षेत्रमा संरक्षित क्षेत्रभित्र करिब ३०.०४ % वन रहेको देखिन आउँछ भने बाँकि ६९.९६% वन सरंक्षित क्षेत्र बाहिर रहेको छ ।

उच्चपहाडीक्षेत्रको करिब ५७.५८% (१,७३२,७५९ हेक्टर) भू-भाग वन क्षेत्रले ओगटेको देखिन्छ भने अन्य काष्ठ तथा बुटयान क्षेत्र करिब १०.९७% भ-ूभागमा बिस्तारित छ । उच्चपहाडी क्षेत्रमा संरक्षित क्षेत्रभित्र करिब २६.९२% (४६६,५३० हेक्टर) वन रहेको देखिन आउँछ भने बाँकि ७३.०८% वन सरंक्षित क्षेत्रबाहिर रहेको छ । त्यसैगरी, उच्च हिमालीक्षेत्रको करिब ५.३७% (१९०,१५० हेक्टर) भू-भाग वन क्षेत्रले ओगटेको देखिन्छ भने अन्य काष्ठ तथा बुटयान क्षेत्र करिब ६.३१% (२२३,२३४ हेक्टर) भू-भागमा बिस्तारित छ । उच्च हिमाली क्षेत्रमा संरक्षित क्षेत्रभित्र करिब ५८.४१% (१११,०७० हेक्टर) वन रहेको देखिन आउछ भने बाँकि ४१.५९% (७९,०८० हेक्टर) वन सरंक्षित क्षेत्रबाहिर रहेको छ ।

वनको अवस्था आंकलन गर्दा संयुक्त रुपमा उच्चपहाडी तथा उच्च हिमालीक्षेत्रमा प्रति हेक्टर औसत विरुवा (seedling) संख्या करिब २,३९९ र औसत लाथ्रा (sapling) को संख्या करिब ८३१ रहेको छ । वन क्षेत्रमा रुखको प्रति हेक्टर औसत संख्या ९८५.६५ देखिन आएको छ भने रुखहरुको १.३ मिटर

उचाइमा लिएको क्षेत्रफल (basal area) ३०.५४ वर्ग मिटर प्रति हेक्टर रहेको छ । यसैगरी वनक्षेत्र, अन्यकाष्ठ तथा बुटयानक्षेत्र र अन्य क्षेत्रमा रुखको आयतन (stem volume) औसतमा क्रमशः करिब २३२.४२, ८.११ र १४.४६ घन मिटर प्रति हेक्टर देखिन आउँछ । उच्चपहाडी तथा उच्च हिमालीक्षेत्रको वनमा औसत कार्वन संचिति करिब २७२.४० टन प्रति हेक्टर अनुमान गरिएको छ जसमा रुख, माटो र पातपतिगंर (litter and debris) को योगदान क्रमशः ५७.६१%, ४१.८६% र ०.५३%, रहेको छ ।

नमुना सर्वेक्षणको क्रममा मध्यपहाडमा कुल २७५ वटा रुखहरुको प्रजाति (१५७ जाति र ७९ परिवार) पाइएको छ । गैरकाष्ठ वन पैदावारको रुपमा ७५५ प्रजातिका बोटबिरुवा र ७८ प्रजातिका जीवजन्तु र तिनका अंगहरु प्रयोगमा आएको अध्ययनबाट देखिन आएको छ । यस क्षेत्रमा चौध प्रकारका प्राकृतिक तथा मानवीय प्रभावहरु देखिएका छन् जसमध्ये चरिचरन र रुखकटान मुख्य रहेको देखिन्छ ।

CONTENTS

1. INTRODUCTION

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 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).

Spatially, High Mountains region extends from 80^{o} 30' 47" to 88^{o} 07' 04" E longitude; and from 26^{o} 59' 15" to 30^{o} 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^{o} 45' 10" to 88^{o} 12' 22" E longitude; and from 27^{o} 22' 54" to 30^{o} 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 the Region ranges from 1,960 m to 8,848 m.

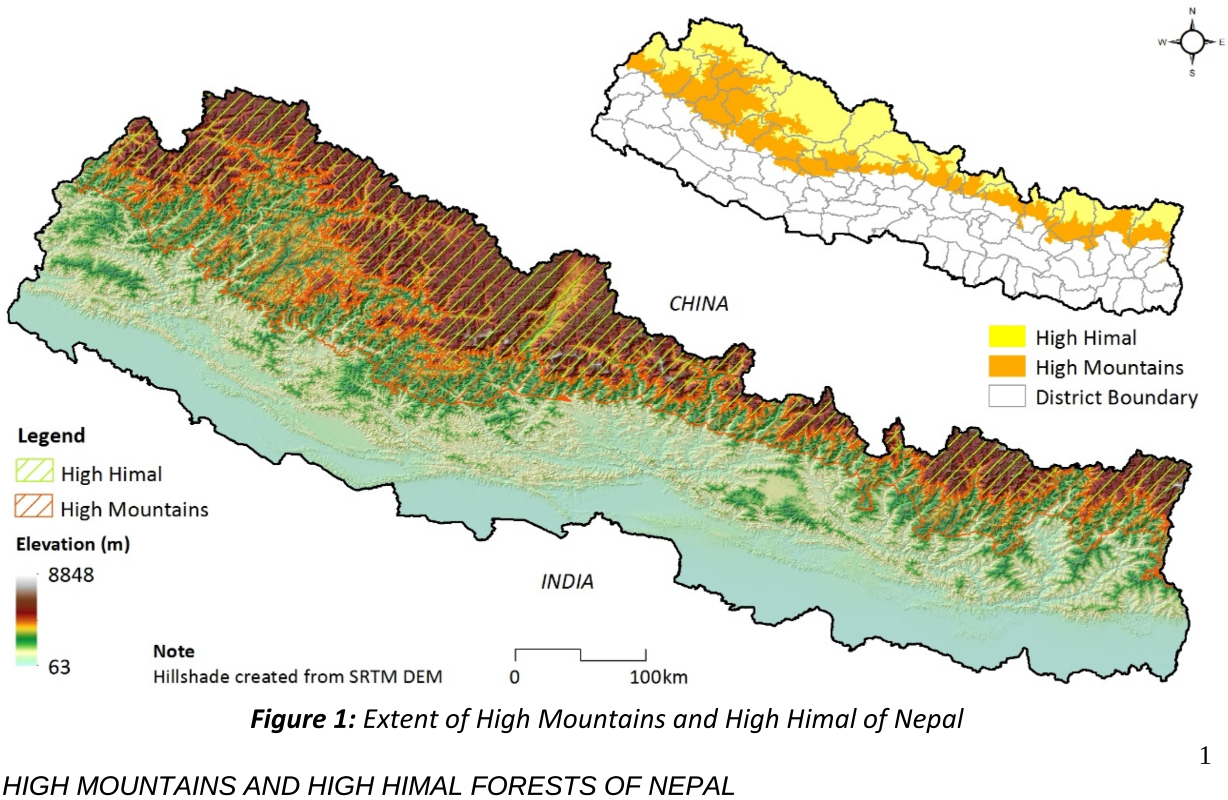

Figure 1: *Extent of High Mountains and High Himal of Nepal*

1.1 Practice of Forest Management in High Mountains and High Himal

High Mountains and High Himal physiographic regions are also generally known as high altitude. The history of the high altitude forest management dates back centuries. The *kipat* and *birta* land tenure systems were established under the Shah and Rana regime dating back to 1768 and were not abolished until after the introduction of democracy in 1951. After the promulgation of the Nationalisation of Private Forest Act (1957), *Birta* Abolition Act (1959), and *Kipat* Abolition Act (1964) traditional land tenure systems were replaced by a division of state land (*raiker*), private land, and land owned by religious groups (*guthi*). Mostly old-growth forests, meadows and rangeland are found in High Mountains and High Himal regions.

In the 1980s, a formal community forestry (CF) programme was launched to prevent forest degradation and to mitigate environmental problems. The Forest Act, 1993 and Forest Regulation, 1995 provided the legal and procedural bases for CFUGs to become local level autonomous forest management bodies.

Forest management at high altitudes is an important agenda of forestry planning and management. Shrestha (2000) highlighted issues of concern regarding high-altitude forests, including the lack of management information and technology. To prevent the depletion of non-timber forest product (NTFPs), the government has banned the collection, sale and transport of several high-altitude species.

Focusing on both the management of high-altitude forest and conservation of biodiversity, Ministry of Forests and Soil Conservation (MFSC) approved the Sacred Himalayan Landscape Strategy (2006–2016) in 2006 (MFSC, 2006). Further, it prepared an Implementation Plan (2010–2014) focusing on thematic areas including biodiversity and habitat management (GoN, 2011). The Government of Nepal approved the National Biodiversity Strategy and Action Plan (NBSAP) in 2014, building on Biodiversity Profiles of Nepal (1996) and Nepal Biodiversity Strategy (2002).

1.2 Population

High Mountains and High Himal regions are sparsely populated with average population densities of about 186 individuals/km^2 and 30 individuals/km^2 , respectively (Figure 2). High Mountains region has about 7.4% (1.97 million) of the total population of the country and High Himal has only about 0.6% (0.18 million) of the total national population. The average household size in High Mountains is 4.94 and 4.68 in High Himal. The composition of population is 48% male and 52% female in High Mountains and 49% male and 51% female in High Himal region.

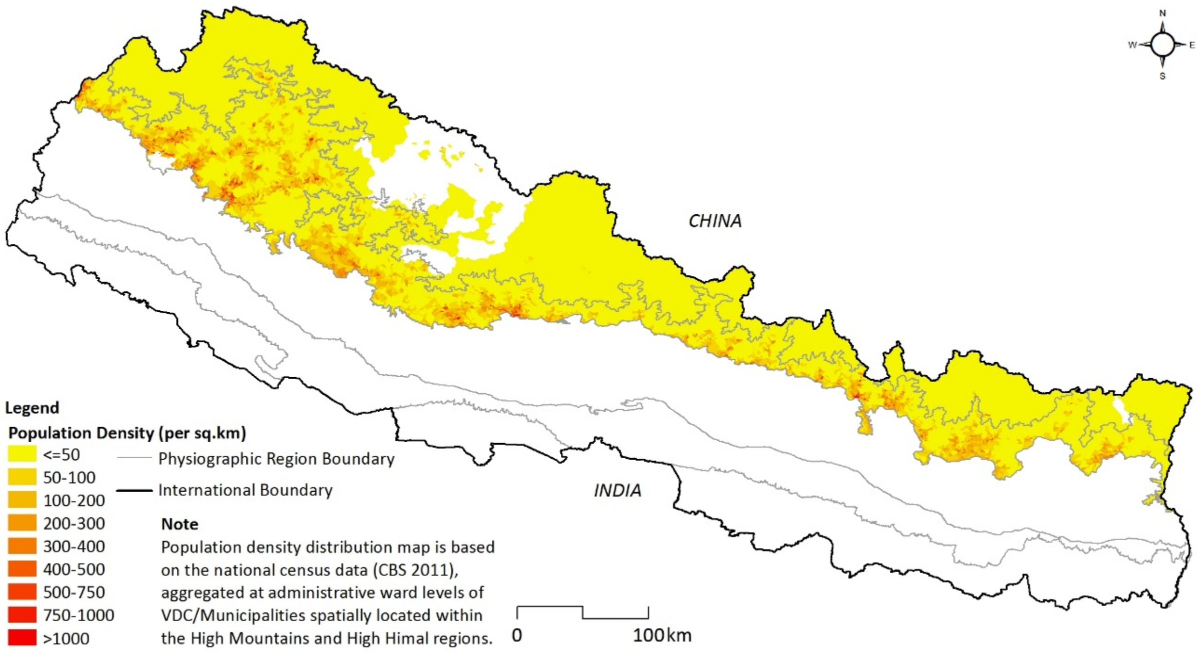

Figure 2: Population density distribution in High Mountains and High Himal (Source: CBS, 2011)

In High Mountains, the highest percentage of population lives in Mid-Western Development Region (36.73%) followed by Far-Western (18.75%), Western (15.84%), Eastern (14.69%) and the least in Central region (14%). Population density is the highest in Far-Western with 252 individuals/km^2 and the lowest in Eastern Development Region with 123 individual/km^2 (Table 1).

Similarly, in High Himal, the highest percentage of population lives in Mid-Western Development Region (41.18%) followed by Western (23.29%), Eastern (13.33%), Central (11.14%) and the least in Far-Western region (11%). Mid-Western Development Region in High Himal has the highest population density of 57 individuals/km^2, with the least density in Far-Western Region with only 11 individuals/km^2 (Table 1).

Table 1: Population characteristics of High Mountains and High Himal by Development Region

Development Region	Male	Female	Total population	%	Household	Avg. household Size	Population density/ km^2
High Mountains							
Far-Western	177,747	192,071	369,818	18.75	66,785	5.54	252
Mid-Western	356,091	368,385	724,476	36.73	133,074	5.44	163
Western	140,803	171,574	312,377	15.84	73,372	4.26	225
Central	133,373	142,540	275,913	13.99	63,830	4.32	201
Eastern	138,596	151,067	289,663	14.69	61,947	4.68	123
Total	**946,610**	**1,025,637**	**1,972,247**		**399,008**	**4.94**	**186**
High Himal							
Far-Western	9,790	9,674	19,464	11.06	3,280	5.93	11
Mid-Western	35,897	36,573	72,470	41.18	13,712	5.29	57
Western	19,837	21,154	40,991	23.29	10,401	3.94	13
Central	9,783	9,828	19,611	11.14	4683	4.19	14
Eastern	11,678	11,775	23,453	13.33	5495	4.27	29
Total	**86,985**	**89,004**	**175,989**		**37571**	**4.68**	**30**

Source: Adapted from CBS (2011)

1.3 Climate

The climate in High Mountains region is quite variable 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 (Figure 3). The climatic regime ranges from warm-temperate in the valleys to cool-temperate in the higher hills and artic in the mountainous region. The average annual maximum temperature[1] is about 20^{o}C (ranging from -12^{o}C to 36^{o}C); with the average annual minimum 7^{o}C (ranging from -18^{o}C to 30^{o}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.

[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.

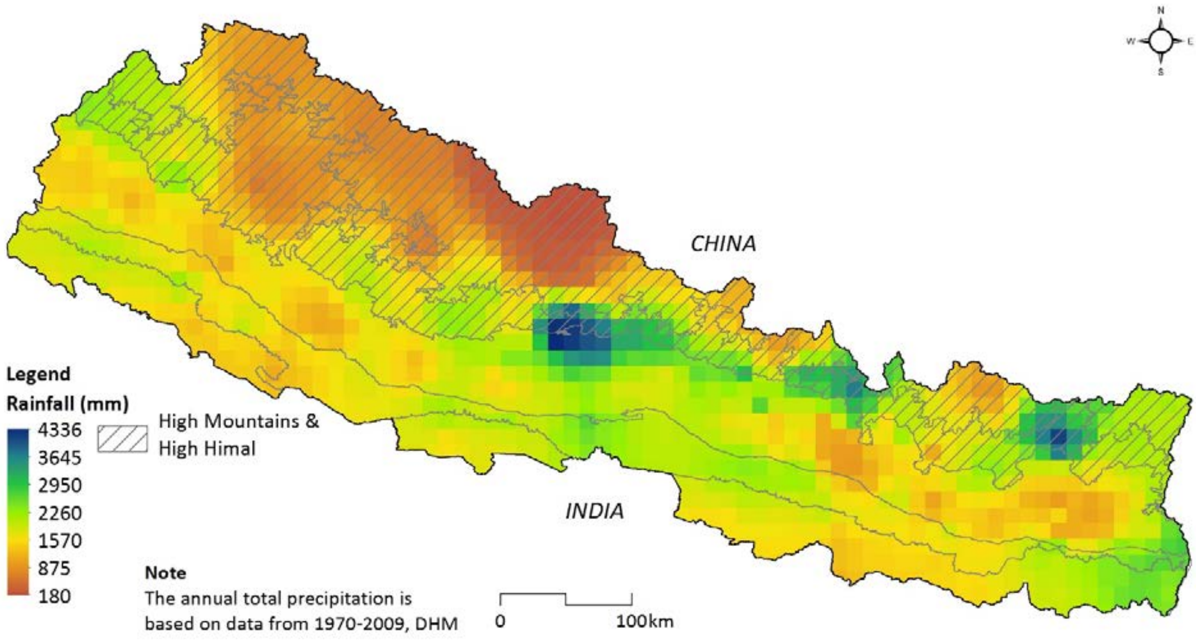

Figure 3: *Total annual precipitation in Nepal (1970-2009, DHM)*

1.4 Geology and Soils

The boundaries between the physiographic regions are defined by changes in geomorphic processes, bedrock geology, climate and relative relief (LRMP, 1986). 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 areas is 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).

1.5 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 (Figure 4).

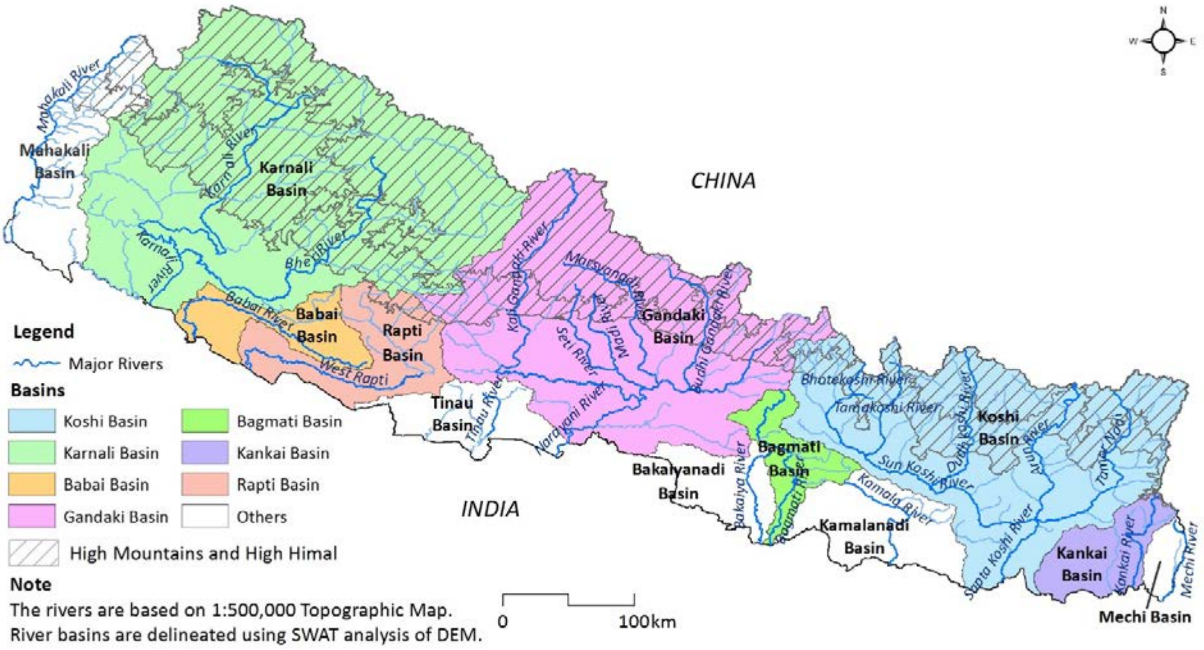

Figure 4: *River basins and drainage system of Nepal*

2. PREVIOUS FOREST RESOURCES ASSESSMENT

The first national-level forest inventory was carried out in the 1960s. Since then, forest resource assessments have been carried out in different periods, each different in terms of purpose, scale, scope, design and technology used. The second national-forest inventory was carried out in 1990s. FRA Nepal (2010–2014) is the third comprehensive national-level forest resource inventory that has been carried out.

2.1 Forest Resources Survey (1963–1967)

The first national-level forest inventory was conducted between 1963 and 1967 with support from USAID (FRS, 1967). It covered areas classified as the Terai, Inner-Terai and Churia Hills, as well as the southern faces of the Mahabharat Range but excluded most of the then Chitwan Division, which was inventoried separately. After classifying forests as either commercial or non-commercial, the survey focused on collecting data from commercial forests, primarily on timber estimates of stock and the domestic consumption of wood products. Methodologically, it used visual interpretation of aerial photographs taken in 1953–1958 and again in 1963–1964, mapping and field inventory. The inventory provided the first comprehensive assessment of commercial forests in the Terai as well as those in adjoining areas and in the hilly region.

2.2 Land Resources Mapping Project (1977–1979)

The Land Resources Mapping Project (LRMP) was a whole-country assessment conducted by using a variety of methods, including interpretation of aerial photographs taken between 1977 and 1979, topographic maps and ground verification. It focused on mapping land cover and land use, producing forest cover maps and assessing the type, size and crown cover of forests. Both high- and low-altitude forests were mapped by crown cover (0–10%, 10–40%, 40–70% and 70–100%); scrubland was mapped separately. Each forest was defined on the basis of dominant species and forest type (coniferous, hardwood, or mixed). Land-use maps at the scale of 1:50,000 were produced by using aerial photographs of 1:12,000 scale (LRMP, 1986).

2.3 National Forest Inventory (1987–1998)

The second National Forest Inventory (NFI) was conducted by Department of Forest Research and Survey (DFRS) with support from the Government of Finland from 1987 to 1998. Using 1991 Landsat TM satellite images of the Terai and aerial photographs of the hills taken in 1989–1992 (DFRS, 1999), it updated data on forest cover as well as forest statistics for all accessible forests, excluding those in Protected Areas. The results were compiled from three types of inventories:- (i) Landsat TM satellite imagery for 14 districts, (ii) a district-wise forest inventory for 10 districts, and (iii) aerial photo interpretation for 51 districts. District-wise forest inventory was used to obtain an estimate of forest and shrub cover in Middle Mountains. In the hills, photo-point sampling was used to estimate forest area as well as to carry out forest inventory in the field. Forest was defined as an area of at least one hectare with a crown cover of 10% or more.

3. METHODOLOGY

3.1 Land Cover Area

Area by land cover classes—Forest, Other Wooded Land (OWL), Other Land (OL)—was estimated by using the forest cover maps derived from analysis of remote sensing data. Also, the results on area by protection category, area by slope classes, area by districts and forest patches were estimated by using the forest cover maps.

3.2 Analysis of Remote Sensing Data

Forest cover maps were prepared by using RapidEye MSS Satellite Imagery (Level 1b, radiometrically corrected), secondary images (Google Earth images, Landsat TM, etc.), ancillary maps (LRMP and topographical maps) and the FRA Nepal field inventory data.

Geometric Correction of Satellite Images

The RapidEye Level 1b imagery (22 scenes covering the regions of High Mountains and High Himal acquired in February–April 2010/11) was ortho-rectified by using Toutin's Model (Toutin, 2004), with ground control points and digital elevation model. The ground control points were collected by using road and river features and the digital elevation model, generated using contours and spot levels from the National Topographical Base Map Data. Independent check points were collected to assess the level of accuracy (Figure 5). The planimetric accuracy of the ortho-rectified images was 9.81 m (≈1.96 pixels RMSE) for the 1,355 ground-control points collected for 48 RapidEye scenes covering the entire nation.

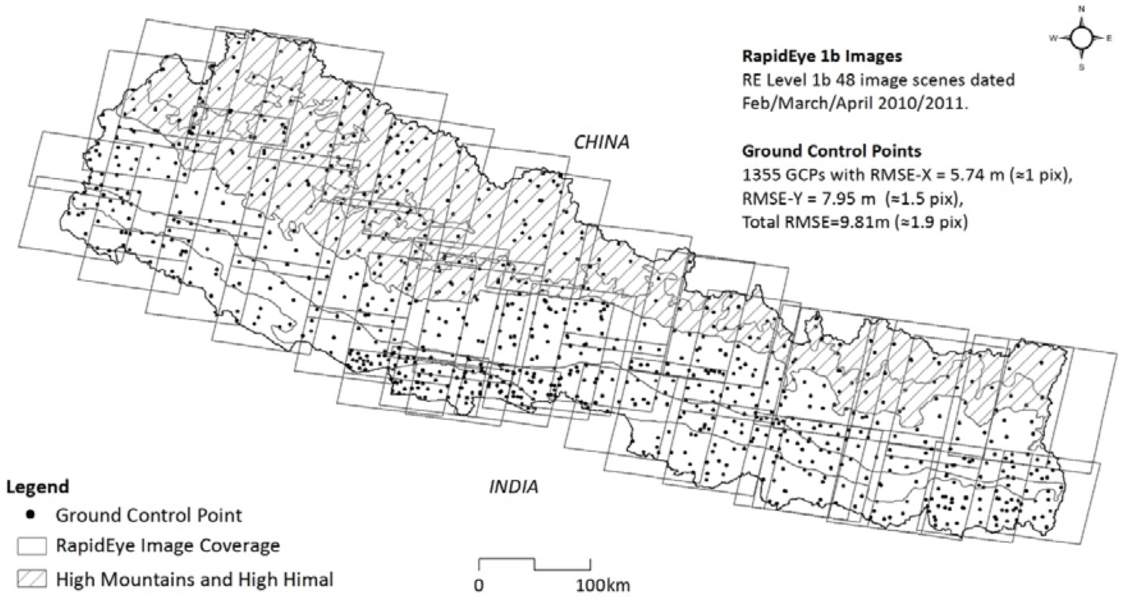

Figure 5: *RapidEye image tiles and ground control points used for mapping*

Atmospheric Correction of Satellite Images

Atmospheric correction was made to minimise the effects of atmospheric haze and terrain shadows by using topographical normalisation and Bidirectional Reflectance Distribution Function (BRDF) correction of the ATCOR3 model (Figure 6), defined by Richter (1998) and given in Equation 1.

Equation 1. *Bidirectional reflectance distribution function (BRDF)*

$$G = (\cos\beta_i / \cos\beta_T)^{1/2}$$

Where,

G = BRDF factor

β_i = incidence angle

β_T = threshold angle

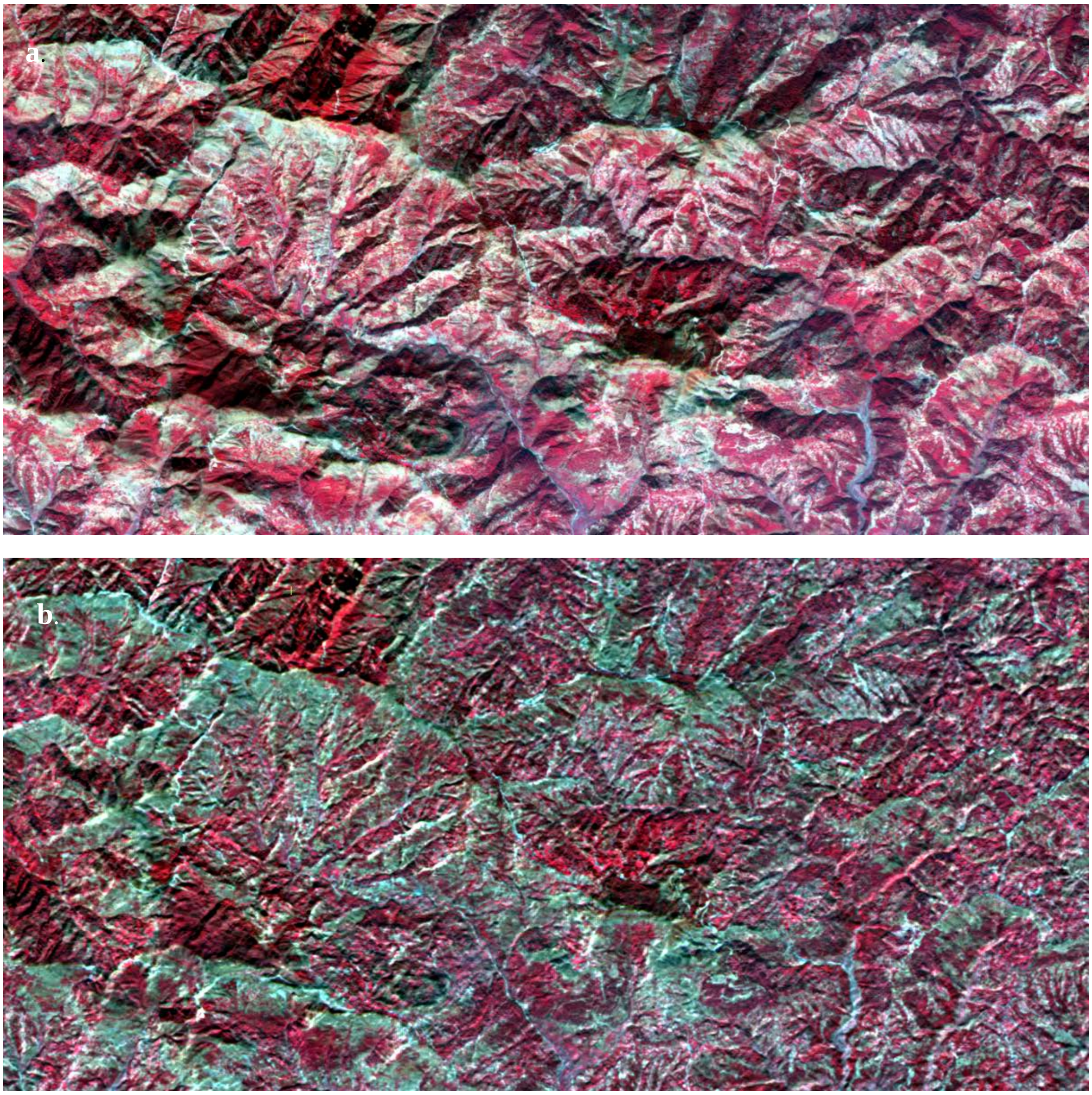

Figure 6: *Atmospheric correction; (a) Image before and (b) after atmospheric and BRDF corrections*

3.3 Forest Cover Mapping

Forest cover was mapped by adopting a hybrid approach which included automated image classification system and extensive visual interpretation (GOFC-GOLD, 2013). Images were classified by applying segmentation (Baatz and Schape, 2000) followed by a machine learning rule-based classification algorithm called Classification and Regression Tree (CART) (De'ath and Fabricius, 2000; Lawrence and Wright, 2001; Matikainen and Karila, 2011; Pal, 2005) for automated classification in eCognition software (Version 8). The CART method was used in High Mountains and High Himal physiographic regions due to the spatial heterogeneity of the forest patches and complexity of terrain landscape that affected the image classification process using previously adopted (in other physiographic regions) image parameter threshold containment membership function. The CART process used the randomly selected Phase I sample plots containing forest cover classes (viz. Forest, Other Wooded Land, Shrubs and Other Land) as training sets. The predictor variables included (i) mean pixel values of green, red, red-edge and near-infrared bands; (ii) a derived Normalised Difference Vegetation Index (NDVI); (iii) principal components; (iv) the homogeneity texture of the near-infrared band and (v) elevation, from the Digital Elevation Model (DEM). Those variables were used to train the segmented image objects in recursive binary regression tree method with three-fold cross-validation iterations. With large number of training sets, this method used machine learning algorithm to classify the image segments into four forest cover classes, thus minimising the errors inherent to other classification approaches in very high terrain and complex landscape.

Further, to improve classification accuracy, on-screen post-classification visual interpretation was carried out on the classified Forest, Other Land and OWL (including shrub) areas by using high resolution images available in Google Earth. Mapping field survey missions, however, could not be undertaken separately due to time limitations and weather conditions during November/December 2014. The mapping works had to rely on the information from the inventory field missions and from very high resolution Google Earth images for cross-validation and error rectification in classification process.

The accuracy of the forest cover map for High Mountains and High Himal was assessed by comparing the area classified as forest cover with 317 randomly selected FRA inventory plots.

Forest Patch Mapping

The forest patches and the sizes of those patches were analysed and mapped over the classified forest cover of High Mountains and High Himal. Spatially contiguous forest patches that fulfilled the criteria for forest were categorised based on their sizes, which ranged from less than 2 ha to greater than 50,000 ha. The frequency of occurrence and total area covered in each size category were analysed to assess the distribution and area of forest fragments.

Distribution of Forests by Slope Class

The slopes of forests were spatially analysed by using a Digital Elevation Model (DEM)[1] created from the national topographic dataset (DoS, 2001). The elevation of each forest pixel (rasterised at a pixel size of 20 m) created from the RapidEye based forest cover were classified into slope groups of <15%

[1]ADEM at 20 m resolution was created using the contours of the national topographic maps and spot height datasets using the ANUDEM algorithm.

(<8.5°), 15–35% (8.5–19.0°), 35–60% (19.0–31.0°), 60–100% (31.0–45.0°), and >100% (>45°) to produce a forest slope map of High Mountains and High Himal. The total forest area under each slope class was also calculated.

3.4 Forest Inventory

FRA Nepal adopted a hybrid approach in the forest inventory by using interpretation of satellite images (with field verification) at the first stage and the measurement of forest characteristics in the field at the second stage. These methods are described below.

Forest Inventory

The inventory design was largely based on the principle adopted for NFI (DFRS, 1999) developed by Kleinn (1994). The design was tested in the field and subsequently revised to improve its functionality. Two-phase systematic cluster sampling was adopted for field data measurement.

Sampling Design

A two-phase systematic cluster sampling was adopted. In the first phase, a 4 km × 4 km grid was superimposed on a high-resolution RapidEye (5m × 5m) satellite image covering the entire country with the help of Google Earth images and topographic maps to create 9,180 clusters (grid-cells), each of which consisted of six concentric circular sample plots, thereby making a total of 55,358 sample plots (Figure 7) to be visually analysed. The 24,554 sample plots (HM: 11,307 and HH: 13,247) in 4,096 clusters (HM: 1,887 and HH: 2,209) which were visually interpreted using standardised procedures (FRA Nepal, 2010). These plots were 300 m apart in east-west direction, whereas plots were laid out 150 m apart in north-south direction to capture higher variability of forest characteristics along the altitudinal gradient (Figure 8). Starting in the southwest of Far-Western Nepal, the clusters were systematically numbered from south to north and west to east.

A total of 4,096 clusters in High Mountains and High Himal were divided into two strata. Clusters in the first stratum (forest stratum) had at least one plot (out of six) under Forest; clusters in the second stratum (zero-forest) had no forest plots out of six. From the first stratum, 188 clusters (HM: 163 and HH: 25) were selected. Similarly, from the second stratum, 52 clusters (HM: 31 and HH: 21) were selected.

From the first stratum, there were 882 forest plots (HM: 773 and HH: 109), 99 (HM: 78 and HH: 21) plots in OWL, and 147 (HM: 127 and HH: 20) were in OL. Similarly, from the second stratum, 72 plots (HM: 49 and HH: 23) were in OWL, and 240 (HM: 137 and HH: 103) were in OL.

During field measurement, 624 sample plots were measured out of 1,440. The remaining 816 sample plots (HM: 607 and HH: 209 could not be inventoried because of non-reachability. Out of the measured sample plots (624), 468 (HM: 421 and HH: 47) were in Forest, 26 (HM: 21 and HH: 5) in OWL and 130 (HM: 115 and HH: 15) in OL.

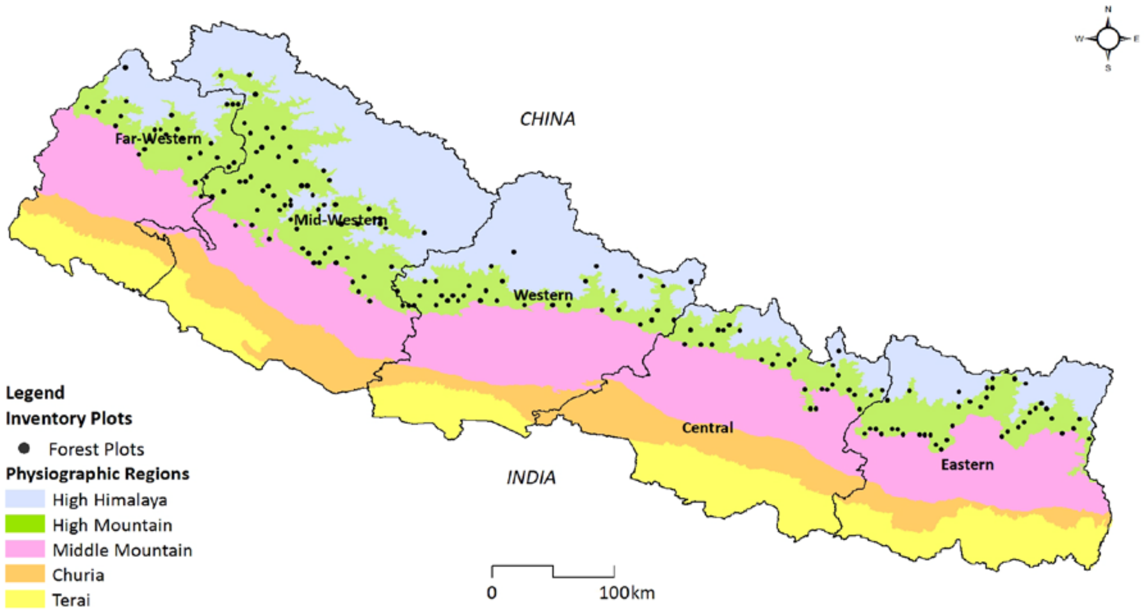

Figure 7: *Distribution of permanent sample clusters in High Mountains and High Himal Regions*

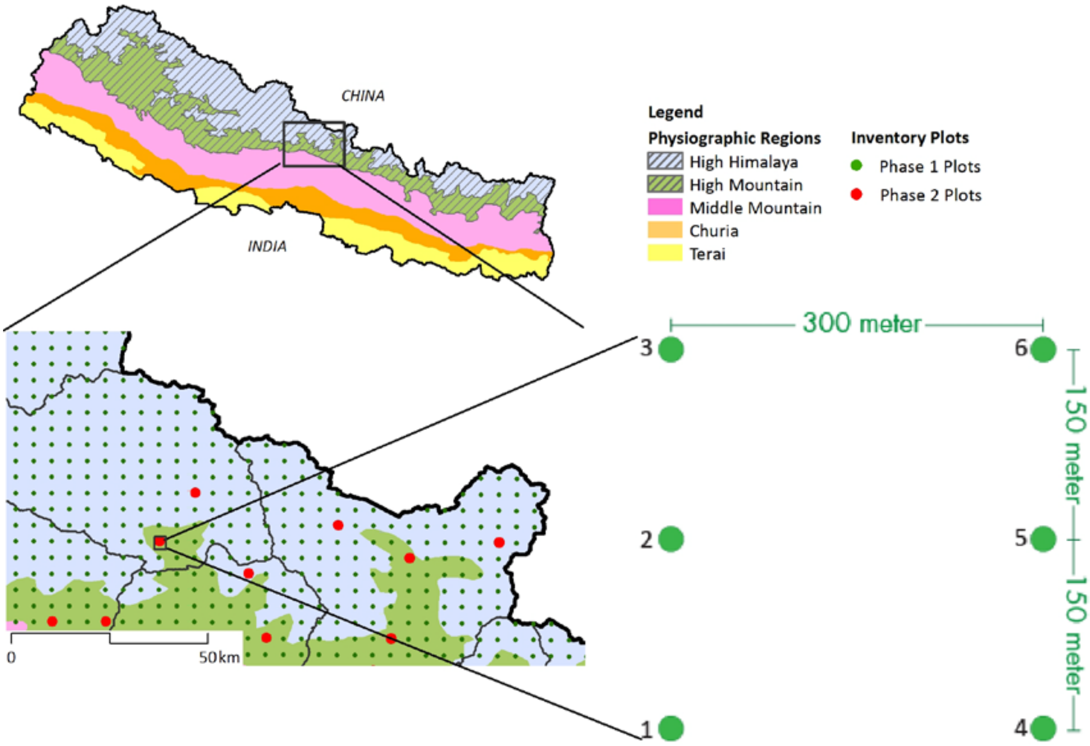

Figure 8: *FRA cluster, sample plot design and layout*

Sample Plot Design

Each sample plot had four concentric circles of different radii, four vegetation sub-plots, four shrubs and seedlings sub-plots, and four soil pits. The plot design for tree measurement is given in the Table 2 and Figure 9.

Table 2: *Size and area of concentric circular plots of different radii with DBH limits*

S.N.	Plot radius (m)	DBH limit (cm)	Area (m^2)
1	20	$\geq$30.0	1256.63
2	15	20.0–29.9	706.86
3	8	10.0–19.9	201.06
4	4	5.0–9.9	50.27

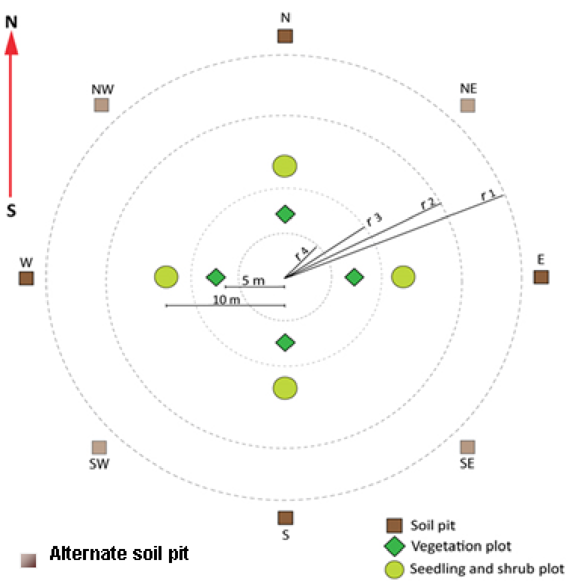

Figure 9: *Layout of concentric circular sample plot*

Other plots were established to assess the status of seedlings, saplings, shrubs and herbs. Seedlings, saplings and shrubs were measured in four circular plots, each with a radius of 2 m, located 10 m away from the centre of the plot in each of the four cardinal directions (north, east, south and west). Species-wise stem counting and mean height estimations were carried out for tree and shrub species having DBH less than 5 cm. Information on non-woody vascular plants was collected from four 1 m^2 plots, each located 5 m away from the 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.

Fourteen categories of natural and anthropogenic forest disturbances were assessed through field observations of their occurrence and intensity (high, medium, low) in the 20 m radius plot. The presence of mammals was assessed through foot prints, scat, calls and markings both inside each 20 m plot as well as outside each plot as teams moved from one plot to the next. Information on soil properties and soil samples was collected from four soil pits dug at the periphery of the outermost circle of CCSP (Figure 10). In many instances topography and ruggedness precluded taking samples from all the soil pits. In such cases, at least one soil pit was prepared and used to take samples. At least one soil pit per forest stand was prepared in order to identity soil texture and determining of soil stoniness. Information related to ethno-botanical uses of different non-timber forest products (NTFPs) was obtained through social surveys conducted in villages near the clusters.

3.5 Tree Resources on Other Wooded Land and Other Land

Information regarding tree resources on OWL and Other Land were obtained by measuring 156 plots (26 OWL and 130 Other Land). They included all plots located in both forest and non-forest strata. The concentric circular plots used for tree assessment were the same as those used in forest plots but no other sub-plots (seedling, sapling, shrubs, herbs and soil) were defined and these were not made permanent.

3.6 Tree Height Modelling

The total height of trees is an important predictor of essential forest parameters such as volume and biomass but its measurement for all trees under forest conditions can be time consuming and impractical. For this reason, height models were prepared for tree species and species groups using data collected from sample trees (every fifth tree) and additional ones if necessary, and tree heights were calculated using the predicted heights from the models.

A non-linear mixed-model approach was used to establish relationships between DBH and total heights of trees by using the "*Lmfor*" package in R Software (Mehtatalo, 2012). As indicated below, different models were developed by using those non-linear functions most suitable for different species (Annex 1). In addition, species with only a few sample trees were grouped according to their morphology, family, genus, and existing height-diameter observations, and models were developed for each of these groups.

A model for predicting tree DBH from stump diameter was also developed so that the volume and biomass of trees that had been felled could be estimated (Annex 2).

3.7 Volume and Biomass Estimation

The volume equations developed by Sharma and Pukkala (1990) and the biomass models prescribed by MPFS (1989) were used to estimate the volume and biomass of standing trees. The air-dried biomass values obtained by using these equations were then converted into oven-dried biomass values by using a conversion factor of 0.91 (Chaturvedi, 1982; Kharal and Fujiwara, 2012). The carbon content was estimated from oven-dried biomass by multiplying the biomass with a carbon-ratio factor of 0.47 (IPCC, 2006).

Stem volume estimation**:** The following allometric equation (Equation 2) developed by Sharma and Pukkala (1990) was used to estimate stem volume over bark:

Equation 2: *Stem volume*

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

where,

ln = Natural logarithm to the base 2.71828.

V = Volume (m^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

Note: Values were divided by 1000 to convert them to m^3.

The regression parameters of Equation 2 are presented in Table 3.

Table 3: *Species-specific coefficients used for calculating the volume 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 ciliate	-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 himalense	-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)

Stem volume without bark (up to top 10 cm and 20 cm) was estimated by using equations developed by Sharma and Pukkala (1990). The volume of individual broken trees were estimated by using a taper curve equation developed by Heinonen *et al.* (1996).

Tree-stem biomass estimation: Tree-stem biomass was calculated by using Equation 3 and species-specific wood-density values (Table 4).

Equation 3: Tree-stem biomass

$$\text{Stem biomass} = \text{Stem vol.} \times \text{Density}$$

where,

Vol. = Stem volume in m^3

Density = Air-dried wood density in kg/m^3

Table 4: Stem-wood density of High Mountains and High Himal's 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 ciliata	480
Cedrus deodara	560
Cupressus torulosa	600
Dalbergia sissoo	780
Daphniphyllum himalense	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); MPFS (1989)

Biomass estimation of tree-branch and foliage**:** The separate branch-to-stem and foliage-to-stem biomass ratios prescribed by MPFS (1989) were used to estimate branch and foliage biomass from stem biomass (Table 5). Dead trees were not taken into account for this estimate.

Table 5: *Branch-to-stem and foliage-to-stem biomass ratios of various tree species*

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 himalense	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**:** Adapted from MPFS (1989)

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

Equation 4: *Total biomass of each individual tree*

Total biomass = Stem biomass + Branch biomass + Foliage biomass

Below-ground biomass: This estimation was done by using default value as recommended by IPCC (2006). The value of 0.25 was used by averaging the values of five different forest types (primary tropical/sub-tropical moist forest = 0.24, primary tropical/sub-tropical dry forest = 0.27, conifer forest having more than 150 t/ha above-ground biomass = 0.23, other broadleaf forest having 75 t/ha to 150 t/ha above-ground biomass = 0.26, and other broadleaf forest having more than 150 t/ha above-ground biomass = 0.24). The biomass of seedlings and saplings having DBH less than 5 cm was not incorporated.

3.8 Reliability of the Results

The mean volume and mean biomass per hectare was calculated by dividing the sum of plot level volume or biomass estimates by the number of sample plots (plot centres). If trees were measured only for a part of the plot (due to non-reachability of the other part of the plot), the plot level volume or biomass was corrected by using the percentage of measured plot. Correction was done separately for each of the four concentric circular sample plots.

The variance of mean volume estimate in forest was estimated by using the variance estimator of a ratio estimator as given in Equation 5 (Cochran, 1977).

Equation 5: *Variance estimator of a ratio estimator*

$$v(\bar{x}^F) = \frac{1}{(\sum^n m_i)^2}\frac{n}{n-1}\sum^n (x_i - \bar{x}^F \cdot m_i)^2$$

Where,

n=number of clusters with at least one forest plot

m_i=number of forest plots in cluster i

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

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

Standard error of estimates was estimated as the square root of the variance.

For other land cover classes (OWL, OL), the variances were estimated with the same formula but replacing the mean volume in forest by the mean volume, number of forest plots and number of clusters with at least one forest plot by the respective values in the class in question.

In practice, the variance estimator of a ratio estimator produces in many cases estimates of variance that are almost equal to the simple variance of cluster means. However, the ratio estimator should be used when the size of clusters is not equal (Cochran, 1977). In this assessment (FRA Nepal) the size of clusters varies because the number of plots in the land cover class in question varies.

The forest types, management regimes, canopy cover, development status, Development Region wise variables were calculated by using respective number of plots in the category.

3.9 Forest Soil Assessment

The top 30 cm layer of soil of each forest stand was sampled and assessed in order to determine soil characteristics and soil organic carbon (SOC) stocks. Field work included the collection of litter and woody debris (wood pieces with diameters less than 10 cm, the smallest diameter of the dead wood fraction), preparation of three or four soil pits per forest stand, identification of soil texture, and determining of soil stoniness. Both the litter and debris and soil samples were collected as composite samples by combining the materials collected at all three or four soil pits (Figure 10).

Organic carbon stock in both the litter and debris fractions were obtained on the basis of the total fresh mass collected from a known area in the field. The dry mass of litter and debris and the SOC content were analysed in the laboratory, then the results calculated per hectare were combined with the characteristics of the forest stand and inventory cluster.

The final SOC value was obtained after correcting laboratory values with a consideration of the degree of stoniness determined in the field. This correction was needed because no organic carbon is found in stones and laboratory analyses give the organic carbon content only for the fine soil fraction (that fraction with particles less than or equal to 0.5 mm in diameter). The FAO (2006) field key for soil texture and stoniness was used. For a correct estimate, the SOC content has to be reduced by the corresponding proportion of stones in soil.

Assessment of Composite Samples of Litter and Woody Debris

Litter and debris fractions were collected from 1 m^2 circular spots located on the surface of each soil pit before it was dug. Litter and woody debris were collected in separate plastic bags, combining the respective fractions collected from all three or four sub-sampling spots in the same bags as composite samples representing the forest stand as a whole. A value of zero was recorded for spots without any litter or debris on the soil surface to ensure that the estimate of average litter or woody debris mass per unit area would be correct.

The total fresh masses of both litter and debris were weighed in the field to an accuracy of 1 gram. As the total volume of all 3–4 m^2 (the total of three or four 1 m^2 plots) was very large, small representative sub-samples were set aside so that their dry masses could be determined in the laboratory.

Sampling of Soil

Soil samples were collected from all soil pits. Each pit was dug within a 2 x 2 m area located 1 m outside of the 20 m plot radius and sized to ensure that the samples would be of undisturbed soil.

The samples were collected by using a 100 mm long, slightly conical cylinder corer with a lower diameter of 37 mm (at its cutting edge) and an upper diameter of 40 mm. The volume of each soil sub-sample collected was 107.5 cm^3.

A composite soil sample was collected from each sub-plot; it included soil from each of four soil pits unless the designated pit turned out to be on cropland, a steep slope (>100%), riverbank, or road or in a rocky area or water body. If a cardinal point was inaccessible, the sub-cardinal point (northeast, southeast, southwest, and northwest) clockwise of that point was substituted. In all cases, there were at least three soil-sampling points within each forest stand of each plot, even if there were several stands.

Separate plastic bags were used to collect the composite soil samples for each of the three layers (0–10 cm, 10–20 cm, and 20–30 cm) (Figure 11), and the fresh mass of the composite sample was weighed to an accuracy of 1 gram. The bags were transported from the field to DFRS Soil Laboratory, where they were stored separately in order to facilitate the assessment of the vertical distribution of SOC across the layers.

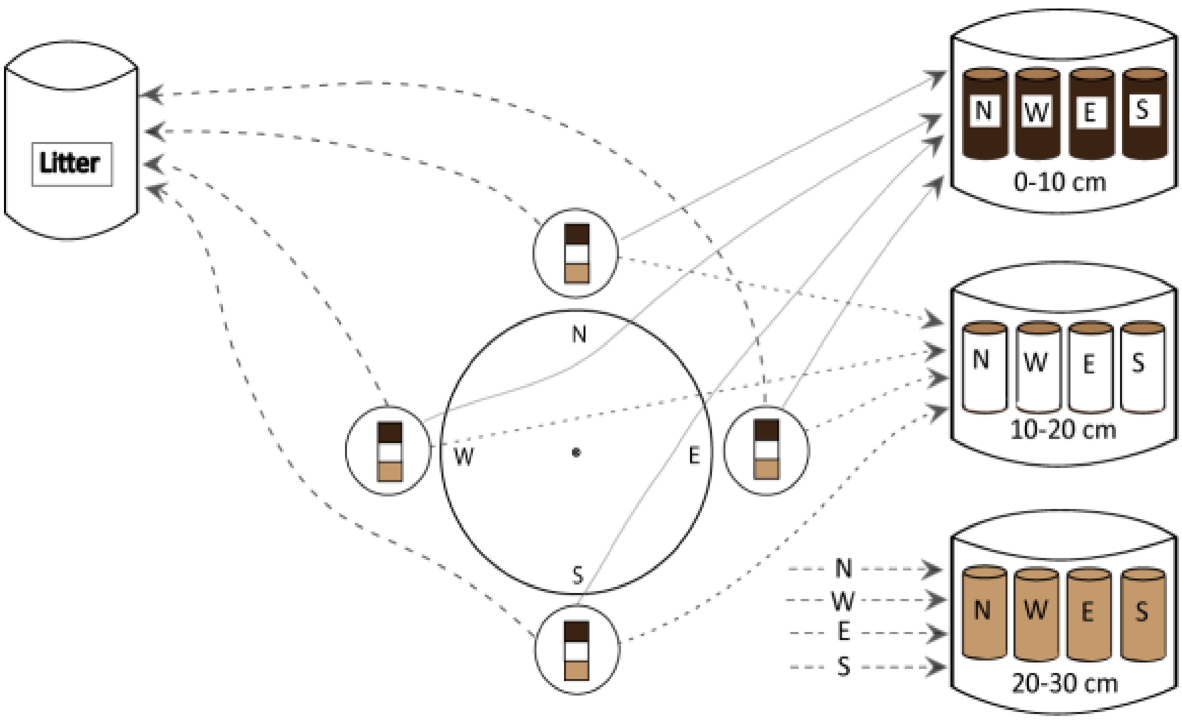

Figure 10: *Collection of composite samples of litter, debris and soil from a plot*

Determination of Soil Characteristics

Soil characteristics, including soil texture and stoniness of the soil pits were observed with the help of FAO's Guidelines (FAO, 2006) (Figure 11**)**. More details on the measurements are given in the FRA Field Manual (FRA Nepal, 2011).

Figure 11: *Soil sample pit*

3.10 Analyses in the Laboratory

Determination of Physical Parameters

The composite samples of soil and sub-samples of litter and woody debris were analysed in the DFRS Soil Laboratory in Babarmahal, Kathmandu. SOC stock was calculated using the dry soil bulk density (g/cm^3) and the proportion of SOC. The dry bulk-density of the fine soil fraction (<2 mm) was determined from the volumetric composite samples in order to calculate the SOC stock in each of the three 10 cm deep layers collected in the field. Soil is void of organic carbon in any portion of the total volume occupied by coarse fraction particles such as pebbles, gravel, and stones. The volume of any large particles, typically less than 20 mm in diameter that were found in the volumetrically cored samples was eliminated when calculating the bulk density of the fine fraction.

Determination of Soil Organic Carbon

The preparation of the samples and the SOC analysis followed the procedures detailed in the Laboratory Standard Operative Procedures (FRA Nepal, 2011), as summarised below.

The ≥2 mm coarse fraction was separated with a 2 mm sieve, and its volume was measured using water displacement. This volume was subtracted in order to calculate the bulk density of the fine fraction. The fine fraction that passed through the 2 mm sieve was further homogenised by sieving it again using a 0.5 mm sieve, and the sieved fine fraction was analysed for OC%.

The soil samples arrived at the laboratory in field moisture conditions, so air drying was used immediately in order to stabilise them. Then they were oven-dried to achieve a constant mass and moisture content. Because of limited supplies of electricity and oven capacity, the oven-drying period was shortened from the conventional duration of overnight to, in some cases, a single hour only. The resultant error that may occur in the dry bulk density figures calculated will be reflected in the final SOC results as well, but because the fieldwork was done during the dry season, the degree of error is considered to be low, especially as air-drying was also used.

Walkley-Black wet combustion method with titration analytics was applied in the analysis of the proportion of SOC. Since the method can recover only about 77% of SOC, a correction factor of 1.33 was applied. An Excel application was produced in order to collect, organise, and speed up laboratory calculations. The application also calculated the carbon stocks of litter, woody debris, and the fine soil fraction.

Litter and woody debris were not analysed for the proportion of organic carbon they contain; instead, the dry mass / fresh mass ratio was used to estimate the dry mass of the total amounts of litter and debris. In order to get a carbon estimate, the total dry mass was multiplied by 0.5, a carbon constant suggested by Pribyl (2010).

Compilation of SOC Stock Estimates

The SOC stock, measured in g/m^2, in the 30 cm topsoil was calculated by using the following equation:

Equation 6: *SOC stock in 30 cm of top soil*

$$SOC_{0\text{-}30\,cm}, g/m^2 = OC_{FF} * BD_{FF} * 300000 * (1 – Stoniness)$$

Where, OC_{FF} denotes the proportion (0–1) of organic carbon (OC) in the soil fine fraction (FF), BD_{FF} is bulk density of soil fine fraction, g/cm^3, 300,000 is the coefficient for volume (cm^3) of the 30 cm deep topsoil layer, and Stoniness denotes the proportion (0–1) of stones per soil volume. The forest stand-wise SOC values obtained were, as convention prescribes, scaled up to t/ha prior to use for reporting.

Soil stoniness was estimated for most sample profiles of High Mountains and High Himal. In the few cases where information was missing, values from the same cluster were applied if available. In cases where no other stoniness estimates were available from the cluster, an average calculated from values representing the same administrative region was used.

Estimation of Mean and Standard Errors

The carbon contents of soil, litter and debris were all calculated using ratio estimates (Cochran, 1977) in order to account for intra-cluster correlations, or, in other words, more pronounced similarities among nearby clusters than among distant clusters.

Quality Assurance of SOC Analysis

In order to validate the soil carbon analysis methodology used by FRA Nepal, the Institutional Cooperation Instrument Nepal-Project compared the SOC results from Terai soil plots determined by DFRS Soil Laboratory and Metla Soil Laboratory in Finland (DFRS/FRA, 2014). DFRS laboratory used the Walkley-Black wet combustion method while Metla laboratory used dry combustion LECO CHN analysis. Because dry combustion methods analyse the CO_2 emitted from a sample burned at a high temperature, they may overestimate SOC if a sample contains inorganic carbonates. For this reason, Metla used hydrochloric acid to eliminate the carbonates and washed out the resultant chlorides with water so they would not harm the analyser (Westman *et al*., 2006).

The results of the two laboratories were consistent for low values of SOC% (0-3%), so there was no need for additional correction coefficients or changes in procedure. However, the results were inconsistent for a single higher organic carbon value (>3%) found in Terai. Comparison with the Metla dry-combustion value suggests that the Walkley-Black DFRS analyses under-estimated the high organic carbon value.

3.11 Biodiversity Analysis

The lists of flora and fauna species obtained from the field sample plots and social surveys (qualitative methods) were verified by using various sources (Edwards 1996; DPR, 2007; *Flora of Nepal* (www.eflora.org), and Bhuju *et al.,* 2007). Annotated lists were prepared by incorporating both sample plot and qualitative data. The social survey was conducted in focus group discussions with executive member of CFUGs, women, dis-advantaged groups, local healers, and NTFPs collectors. Social surveys were conducted in each forest clusters (154 clusters).

Detrended correspondence analysis (DCA) with default options in Canoco 5.01 (Hill and Gauch, 1980; ter Braak and Smilauer, 2012) was used to identify the compositional gradient length in standard deviation units of plots. Multivariate tests of species composition were carried out by using unimodal technique because there was only presence/absence data (Lepš and Šmilauer, 2003) and gradient length was very long (14.10), so the Canonical Correspondence Analysis (CCA) was used to show the relationship between species and environmental variables. The significance of the predictors was tested by using Monte Carlo permutation test.

Frequencies of tree species (the proportion of sampling units containing a given tree species) were calculated using Equation 7.

Equation 7: *Tree species frequency*

$$f = \left(\frac{n_i}{N}\right) \times 100$$

Where,

f_i = Frequency of species *i*

n_i = Number of plots on which species *i* occurred, and

N = Total number of plots studied

Alpha diversity (α) was calculated using Equation 8.

The Shannon-Weaner diversity index was used to calculate species diversity as shown in Equation 10**.**

Equation 8: *Shannon-Weaner diversity index*

$$\overline{H} = -\sum_{i=1}^{s} (p_i)(ln\ (p_i))$$

Where,

$\overline{H}$ = Shannon-Weaner index of diversity (for trees and shrubs)

P_i = Proportion of total number of individual of species *i*(n_i/N)

S = Total number of individual species

n_i = Number of individual species *i*, ranging from 1to S.

N = Total number of all species

ln = Natural logarithm

3.12 Forest Disturbances

Fourteen types of disturbances at four level of intensities were assessed based on 468 sampled plots (each with a 20 m radius).

Forest disturbances were categorised as follows.

No disturbance: No signs of significant disturbance observed

Landslide: Signs of landslide and/or flooding observed

Grazing: Presence of hoofmarks and dung of animals, broken tops of seedlings and saplings, signs of trampling, disturbed forest litter

Lopping: Cutting of side branches of trees for fodder

Leaf litter collection: Collection of dead leaves on the forest floor

Bush cutting: Sign of cutting shrubs and bushes.

Forest fire: Sign of forest fire observed caused by natural and human activities

Encroachment: Encroachment on forest for cultivation and plantation

Resin tapping: Tapped trees, ordinarily pines, were identified by cuts made in the boles of trees to enable resin to ooze out

***Lathra* cutting:** Cutting of saplings and poles up to 30 cm DBH

Tree cutting: Cutting of trees ≥30 cm DBH

Insect attacks: Plant leaves with signs of insect attacks (e.g. holes, nests, etc.)

Plant parasites: Presence of parasitic plants in trees

Plant disease: Disease caused mainly by fungi (e.g. black rot) or bacteria (e.g. rotting). If a tree was rotting due to resin-tapping the disturbance was recorded as resign-tapping, not as plant disease

Wind, storm, hail: Sign of trees broken and erosion on forest floor caused by wind, storm, hail.

Other human-induced disturbances: Disturbances by humans other than those described above (e.g. removing the bark from the base of a tree, snaring, foot trails, forest roads, etc.)

The intensity levels of the above-mentioned disturbances were classified as below:

Intensity level 0: No significant disturbance

Intensity level 1: Minor disturbance (little or no effect on trees and regeneration, less than 10% of trees and seedlings affected)

Intensity level 2: Moderate disturbance (tangible effect on trees and regeneration, 10–25% of trees and seedlings affected)

Intensity level 3: Severe disturbance (significant effect on trees and regeneration, more than 25% of trees and seedlings affected)

4. TECHNICAL CHALLENGES AND LIMITATIONS

4.1 Remote Sensing

Visual Interpretation in Phase-1 Plot Sampling

On-screen visual interpretation as a pre-processing step makes it possible for an interpreter to easily integrate the different characteristics of objects (e.g. surface texture) visible in an image and benefit from direct knowledge of the context. Unlike digital classification methods, such interpretation does not require specialised software though it did face the following challenges:

- Some of the images interpreted in 2010 were partly from 2003–2005, and land-cover changes in the intervening years could have caused discrepancies with fieldwork results.
- Google Earth Images might have some local geometrical distortions which can lead to misinterpretation of the boundaries between two land-cover types, and visual interpretation may be distorted by human error in classifying land cover.

4.2 Forest Cover Mapping

Remote sensing-based mapping of vegetation and its types is a challenging task to begin with and these challenges are exacerbated by the difficult and varied terrain and climate of Nepal. With a scientific and technically sound approach, appropriate remote sensing materials and the support of reliable and extensive ground samples, multi-source mapping of vegetation/forest can be achieved with a good degree of accuracy and reliability. FRA Nepal faced several technical limitations and challenges while mapping forest and non-forest areas in High Mountains and High Himal regions. The limitations encountered during the mapping process were:

- The fact that image acquisition months (December, February, March and April) varied means that atmospheric conditions differed, thus creating challenges for carrying out atmospheric correction and normalising for automated image analysis. The challenges were further due to very steep terrain resulting in terrain shadow effects and error of occlusion in the high resolution satellite imageries. Complete removal of the terrain shadow effect could not be achieved by using standard BRDF functions, which may also have contributed to certain errors in forest cover mapping.
- The spatial heterogeneity of forest stands and the fuzziness of their boundaries might have introduced errors into their classification and delineation in the mountainous terrain.

- Mapping of shrub areas was extremely challenging due to the limitations of the images used and the insufficiency of field reference data. Mapping of shrubs had to rely on visual interpretation method with the aid of very high Google Earth imageries as ancillary data to supplement automatic classification through Classification and Regression Tree (CART) machine learning method by using Phase I plots in High Mountains and High Himal.
- Due to in-accessibility, independent ground verification for mapping was not conducted. Instead, the validation works had to rely heavily on visual interpretation and validation through Google Earth and independent assessment using inventory forest plots. This independent assessment using inventory sample plots measured on the ground provided sufficient ground truth to assess the accuracy of the mapped classes and validate the results.
- Similarly, differentiating OWL (including shrub) was made difficult by the limitations of the images used, so misclassification of OWL to shrub or vice versa cannot be ruled out.
- Young regeneration and recent plantation might have been classified as Other Land because they are not spectrally different from the surrounding land cover.
- The forest cover mapping result could not be comparable with the previous National Forest Inventory (DFRS, 1999) due to methodology differences.

4.3 Forest Inventory

The methodology was designed to collect national level data on per hectare stem volume and biomass of forests with 10% accuracy at 95% confidence limit. This is the reason why reliability of the other findings (number of stems and volume by species, forest type, quality class; number of seedling and sapling, NTFPs; biodiversity; soil carbon, etc.) may not be within the target accuracy level and they are indicative values. Also, the confidence levels for sub-populations, such as individual Development Regions could be lower (FRA Nepal, 2010).

About 57% sample plots could not be measured because of non-reachability and other different constraints. Due to insufficient number of sample plots measured in each physiographic region (HM and HH), the data of those two regions was combined for analysis and reporting. The forest types and species composition of both the regions are similar and the number of measured sample plots in both the physiographic regions are in proportion to their respective total forest area. In addition, quality assurance of forest inventory could not be conducted.

It is extremely difficult to conduct a temporal analysis of forest parameters without well-established permanent samples plots and well-documented base line data. Another problem is that errors in the values being compared may be large in comparison with the changes measured. The data analysis relied on biomass equations developed by Sharma and Pukkala (1990). Sharma and Pukkala did not provide species-specific wood densities for all tree species and offered stem-to-branch and stem-to-foliage biomass ratios for only a few tree species. Besides, the values in the biomass tables were only for air-dried biomass. All of these limitations made it difficult to precisely estimate the above- and below-ground biomass and carbon content in both HM and HH forests.

4.4 Soil Organic Carbon Analysis

Deodar, Sal and *Juniper* forest types were represented only by three, two and one stands in the soil sampling, respectively, and SOC or litter and woody debris results from those forest types cannot be reliably extrapolated for larger areas. Soil carbon inventory is overall weaker than forest inventory in predicting SOC stocks on the basis of different forest areas. However, the symmetry of distribution of SOC stocks, indicated e.g. by close values of mean and median, allows for a sound estimation of forest soil carbon stocks in the area of both physiographic regions, High Mountains and High Himal. In spite of spatial uncertainties, the importance of soil organic carbon stock is undeniable. It is also good to remember that the present inventory only gives information of the topmost 30 cm soil layer carbon stocks, and probably the deeper layers would significantly add to the stock. In High Mountains and High Himal the soil depth may be lower than that in lower physiographic regions due to steepness of the forest sites and bedrock outcroppings, limiting the accumulation of SOC stocks. However, soils shallower than 25 cm represented only less than 25% of the studied forest stands and more than 50% of stands had deeper than 50 cm of active soil layer.

Although the design for soil sample collection consisted of taking 3–4 sample pits from each sample plot, it was not always possible in the field. Therefore, the sample was collected even when sample from only one pit was possible. Further, not a single sample could be collected from some sample plots which were naturally low-carbon containing plot. This is why, while calculating carbon content, there could have been systematic biases at two stage. The implication is that the result of soil carbon may have been exaggerated.

4.5 Biodiversity Assessment

The main limitation of the biodiversity assessment was the very low sampling intensity (<0.0030%), which suggests that it is likely that sparsely distributed species were missed. The species richness value and index included information about woody plants, climbers, and epiphytes, but the values and indexes for herbaceous plants and other taxa might be erroneous because such species are seasonal. In addition, the biodiversity data was collected as a part of tree level inventory based on sampling design for forest inventory, so the methodology might not be adequate for complete assessment of biodiversity. Further, participatory social method was applied for qualitative information of biodiversity, which depended solely on the informants' knowledge.

4.6 Forest Disturbance

Whilst standard guidelines were issued for categorisation of forest disturbance, this work still faced some unavoidable limitations. For example:

- Classification of the intensity of impact requires some personal judgement, which may vary between crews; and this judgement could also be influenced by the season of data collection.
- Fire scars were more apparent during the winter dry season than immediately after the monsoon rains.

5. RESULTS

5.1 Land Cover Mapping

Land Cover in High Mountains and High Himal

According to land cover mapping, High Mountains (HM) and High Himal (HH) region extend over 6,548,766 ha. Other Land cover the greatest proportion (62.19%; 4,072,426 ha), followed by Forest (29.36%; 1,922,909 ha) and Other Wooded Land (8.45%; 553,431 ha). Forest and OWL together cover 37.81%; (2,476,340 ha) in the combined HM–HH region.

In High Mountains region, 57.58% (1,732,759 ha) of the total land is covered by Forest and 10.97% (330,197 ha) by OWL, making a total of 68.55% covered by Forest and OWL (Table 7). In High Himal region, Forest covers 5.37% (190,150 ha) and OWL 6.31% (223,234 ha). Forest and OWL together cover 11.68% in HH region (Table 6). For the purpose of calculating inventory results, the areas of OWL (484,357 ha) and OL (1,197,005 ha) under 4,000 m elevation were used.

Table 6: *Area by land cover class in High Mountains and High Himal*

Land cover class	High Mountains		High Himal	
	Area (ha)	**(%)**	**Area (ha)**	**(%)**
Forest	1,732,759	57.58	190,150	5.37
Other Wooded Land (OWL):				
- Tree crown cover (5–10%)	260,466	8.65	213,384	6.03
- Shrub	69,731	2.32	9,850	0.28
OWL sub-total	330,197	10.97	223,234	6.31
Other Land	946,561	31.45	3,125,865	88.32
Grand Total (Forest + OWL + Other Land)	**3,009,516**	**100.00**	**3,539,249**	**100.00**

The spatial distribution of Forest in High Mountains and High Himal is presented in Figure 12. District-level forest cover maps of High Mountains and High Himal regions are presented in Annex 3.

Land Cover of High Mountains by Regions and Districts

Mid-Western Development Region has the highest proportion of Forest with 608,443 ha (35.11%) followed by Eastern with 329,608 ha (19.02%), Western with 297,981 ha (17.20%), Far-Western with 254,027 ha (14.66%) and Central Development Region with 242,700 ha (14.01%). The largest area of OWL (99,562 ha i.e. 38.22% of the total OWL area) and shrub (43,569 ha i.e. 62.5% of the total shrub area) was found in Mid-Western Development Region. The distribution of land cover by district and region is given in Table 12.

Table 7: *District-wise land cover type in High Mountains in 2010 (area in ha)*

Development Region	District	Forest	Other Land	OWL*	Shrub	Grand total
	Bhojpur	15,050	5,954		665	21,669
	Ilam	3,329	901	335	17	4,582
	Khotang	15,113	11,395		674	27,182
	Okhaldhunga	15,546	8,741	367	89	24,744
Eastern	Panchthar	9,974	1,361	679		12,014
	Sankhuwasava	100,374	32,434	17,429	3,664	153,901
	Solukhumbu	78,498	50,527	1,060	10,422	140,508
	Taplejung	90,183	32,395	17,894	112	140,584
	Terhathum	1,542	295	519		2,356
Total		**329,608**	**144,003**	**38,284**	**15,643**	**527,538**
	Dolakha	63,729	26,510	2,749	135	93,123
	Nuwakot	12,945	7,036	519		20,500
Central	Ramechap	19,040	8,922	995		28,957
	Rasuwa	46,406	22,281	2,073	158	70,918
	Sindhupalchowk	75,677	38,208	1,162	70	115,117
Total		**242,700**	**119,263**	**9,947**	**363**	**372,271**
	Baglung	62,292	43,146		2,129	107,567
	Gorkha	59,631	27,065	9,011	202	95,910
	Gulmi	43	128		3	174
	Kaski	42,233	12,039	6,035	4	60,310
Western	Lamjung	47,318	16,206	3,398	106	67,028
	Manang	7,184	3,555	967	377	12,083
	Mustang	1,812	1,427	606		3,845
	Myagdi	70,748	36,242	8,837	5,862	121,690
	Parbat	6,721	4,024	742	140	11,627
Total		**297,981**	**143,832**	**29,596**	**8,824**	**480,234**
	Dailekh	23,889	7,633	611	3,443	35,575
	Dolpa	54,805	33,376	26,814		114,994
	Humla	69,755	47,071	18,403		135,229
	Jajarkot	86,542	44,007	4,309	8,852	143,710
Mid-Western	Jumla	83,637	61,267	8,468	11,870	165,242
	Kalikot	96,075	48,342	7,136	12,579	164,133
	Mugu	68,542	38,639	27,256		134,437
	Pyuthan	6,986	6,528		84	13,598
	Rolpa	22,548	31,271		673	54,492
	Rukum	95,665	89,090	6,565	6,069	197,388
Total		**608,443**	**407,224**	**99,562**	**43,569**	**1,158,798**
	Achham	14,323	8,082	6,501		28,907
	Baitadi	813	838	597		2,249
Far-Western	Bajhang	86,686	38,669	26,547	57	151,958
	Bajura	90,856	55,859	31,985	1,275	179,976
	Darchula	52,014	28,003	16,948		96,965
	Doti	9,335	787	499		10,621

Total		254,027	132,239	83,077	1,331	470,675
Grand Total		**1,732,759**	**946,561**	**260,466**	**69,731**	**3,009,516**

*Crown cover 5–10% of tree species

Land Cover of High Himal by Region and District

The total area of Forest in High Himal region is 190,150 ha. In terms of the proportion of the total forested area in each Development Region, Western Development Region has the most forested area with 59,538 ha (31.31%). It is followed by Mid-Western with 53,679 ha (28.23%), Eastern with 31,939 ha (16.80%), Far-Western with 23,570 ha (12.40%) and Central with 21,424 ha (11.27%) forest areas. Mid-Western Development Region has the largest area of OWL (79,823 ha i.e. 37.41% of the total OWL area) and Shrub (5,676 ha i.e. 57.63% of the total Shrub area) are (Table 13). District-wise distribution of land cover types is presented in Table 13.

Table 8: *District-wise land cover type in High Himal in 2010 (area in ha)*

Development Region	District	Forest	Other Land	OWL*	Shrub	Grand Total
Eastern	Sankhuwasava	12,540	86,437	14,711		113,687
	Solukhumbu	8,243	174,154	12,293		194,689
	Taplejung	11,156	159,488	14,451	129	185,224
Total		**31,939**	**420,079**	**41,454**	**129**	**493,600**
Central	Dhading	2,652	11,419	3,171		17,242
	Dolakha	10,877	55,802	7,795		74,474
	Nuwakot	331	3,994			4,325
	Ramechap	2,785	15,331	2,391		20,506
	Rasuwa	2,756	71,640	2,658		77,054
	Sindhupalchowk	2,023	53,447	154	21	55,645
Total		**21,424**	**211,633**	**16,169**	**21**	**249,247**
Western	Baglung	898	14,005	57	2	14,961
	Gorkha	14,867	142,962	12,906	375	171,110
	Kaski	10,002	60,610	844	364	71,820
	Lamjung	5,486	25,546	1,159	223	32,413
	Manang	10,210	200,597	8,755	394	219,956
	Mustang	9,955	326,451	13,930	2,189	352,525
	Myagdi	8,121	82,973	13,422	18	104,535
Total		**59,538**	**853,144**	**51,072**	**3,565**	**967,320**
Mid-Western	Dolpa	16,755	639,490	18,875	4,363	679,483
	Humla	11,962	426,491	27,228	313	465,994
	Jajarkot	3,678	14,818	1,601		20,097
	Jumla	9,204	72,920	7,947	206	90,276
	Mugu	8,201	165,115	14,921	757	188,993
	Rukum	3,879	57,505	9,252	38	70,674
Total		**53,679**	**1,376,339**	**79,823**	**5,676**	**1,515,518**
Far-Western	Bajhang	11,030	137,030	12,625	424	161,110

Bajura	3,368	38,480	7,296		49,144
Darchula	9,171	89,160	4,944	34	103,309
Total	**23,570**	**264,670**	**24,865**	**458**	**313,563**
Grand Total	**190,150**	**3,125,864**	**213,384**	**9,850**	**3,539,248**

** Tree cover: 5–10%*

Forest Cover Inside and Outside Protected Areas

Out of the total 1,922,909 ha of Forest in High Mountains and High Himal, 69.96% falls outside PAs and 30.04% inside PAs. Out of 30.04% Forest in PAs, 23.88% is in Core Area and 6.16% is in Buffer Zones.

Out of the total 1,732,759 ha of Forest in High Mountains, 73.08% (1,266,229 ha.) falls outside PAs, and 26.92% (466,530 ha.) inside PAs. Out of the total area within PAs, 76.03% area is in Core Area and 23.97% area in Buffer Zones (Table 7). Within the PAs in High Mountains, the distribution of Forest is presented in Table 10.

Table 9: Forest cover inside and outside Protected Areas (ha) in High Mountains

Development Region	Inside Protected Areas		Outside Protected Areas	Total area	Percentage
	Buffer Zones	Core Area			
Eastern	51,901	49,581	228,126	329,608	19.02
Central	30,191	118,558	93,950	242,700	14.01
Western	~0	99,383	198,599	297,981	17.20
Mid-Western	23,738	21,727	562,978	608,443	35.11
Far-Western	6,012	65,438	182,576	254,027	14.66
Grand total	111,843	354,687	1,266,229	1,732,759	100.00
Percentage	6.45	20.47	73.08	100.00	

Table 10: *Forest cover inside Protected Areas (ha) in High Mountains*

Development Region	PA/BZ Names	Total Area
Eastern	Kanchanjunga CA	32,208
	Makalu Barun NP	17,364
	Makalu Barun NP BZ	47,839
	Sagarmatha NP BZ	4,071
Total		**101,482**
Central	Gaurishankar CA	84,580
	Langtang NP	33,979
	Langtang NP BZ	30,191
Total		**148,750**

Western	Annapurna CA	76,827
	Dhorpatan HR	9,424
	Manasulu CA	13,131
Total		**99,383**
Mid-Western	Dhorpatan HR	11,177
	Rara NP	6,682
	Rara NP BZ	10,456
	Shey Phoksundo NP	3,868
	Shey Phoksundo NP BZ	13,282
Total		**45,465**
Far-Western	Api Nampa CA	47,784
	Khaptad NP	17,655
	Khaptad NP BZ	6,012
Total		**71,450**
Grand Total		**466,529**

CA = Conservation Area, NP = National Park, HR= Hunting Reserve, BZ = Buffer Zone

Similarly, in High Himal region, out of the total 190,150 ha of Forest, 41.59% (79,080 ha) falls outside PAs, and 58.41% (111,070 ha.) inside PAs. Out of the total Forest within PAs, 94.13% is in Core Area and 5.87% in Buffer Zones (Table 9). The distribution of forested areas in the PAs in HH is presented in Table 12.

Table 11: *Forest cover inside and outside Protected Areas (ha) in High Himal*

Development Region	Inside Protected Areas		Outside Protected Areas	Total area	Percentage
	Buffer Zones	Core Area			
Eastern	3,009	18,032	10,898	31,939	16.80
Central	~0	16,841	4,583	21,424	11.27
Western	~0	46,320	13,218	59,538	31.31
Mid-Western	3,508	14,189	35,983	53,679	28.23
Far-Western	~0	9,171	14,399	23,570	12.40
Grand total	6,517	104,553	79,080	190,150	100.00
Percentage	3.43	54.98	41.59	100.00	

Table 12: *Forest cover inside Protected Areas (ha) in High Himal*

Development Region	Protected area/Buffer zone	Total Area
Eastern	Kanchanjunga CA	6,178
	Makalu Barun NP	9,932
	Makalu Barun NP BZ	1,785
	Sagarmatha NP	1,922
	Sagarmatha NP BZ	1,224

Total		**21,041**
Central	Gaurishankar CA	14,107
	Langtang NP	2,734
Total		**16,841**
Western	Annapurna CA	32,324
	Dhorpatan HR	2,369
	Manasulu CA	11,627
Total		**46,320**
Mid-Western	Dhorpatan HR	2,294
	Shey Phoksundo NP	11,895
	Shey Phoksundo NP BZ	3,508
Total		**17,697**
Far-Western	Api Nampa CA	9,171
Total		**9,171**
Grand Total		**111,070**

CA = Conservation Area, NP = National Park, HR= Hunting Reserve, BZ = Buffer Zone

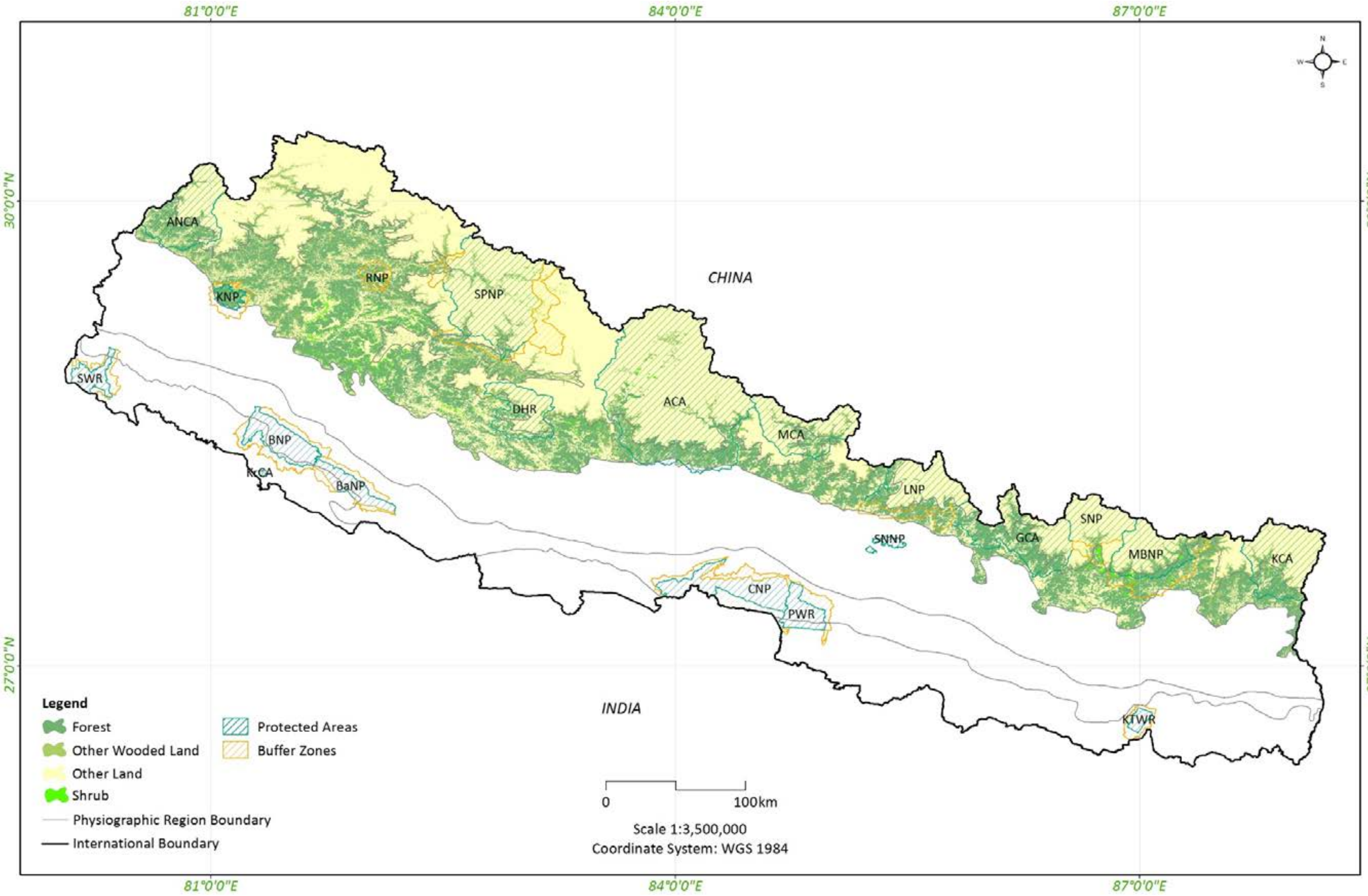

Figure 12: *High Mountains and High Himal forests*

Forest Cover by Slope Class

About half (48.88%) of High Mountains forest cover is in 60–100% slope class (Table 11). Similarly, 52.72% of High Himal's forest cover is in 35–60% slope class (Table 11 and Figure 13). Steep slopes, existence of Protected Areas and associated Buffer Zones, and poor access limit the potential production of saw logs in High Mountains and High Himal forests. Tree harvesting using human and draught animals on erosion prone sites should be limited to slopes of less than 35% (FAO, n.d.). Thus, potential production forest lying outside Protected Areas and with a maximum slope of 35% was found to be 255,038 ha (i.e. 13.26% of total Forest cover).

Table 13: *Area of High Mountains and High Himal forests by slope class*

Slope class (%)	Slope class (º)	High Mountains		High Himal	
		Area (ha)	Percentage	Area (ha)	Percentage
<15%	<8.5	25,501	1.47	12,226.00	6.42
15–35%	8.5–19.0	141,897	8.18	75,413.60	39.61
35–60%	19.0–31.0	496,270	28.60	100,385.48	52.72
60–100%	31.0–45.0	848,015	48.88	2,373.00	1.25
>100%	>45.0	223,232	12.87		

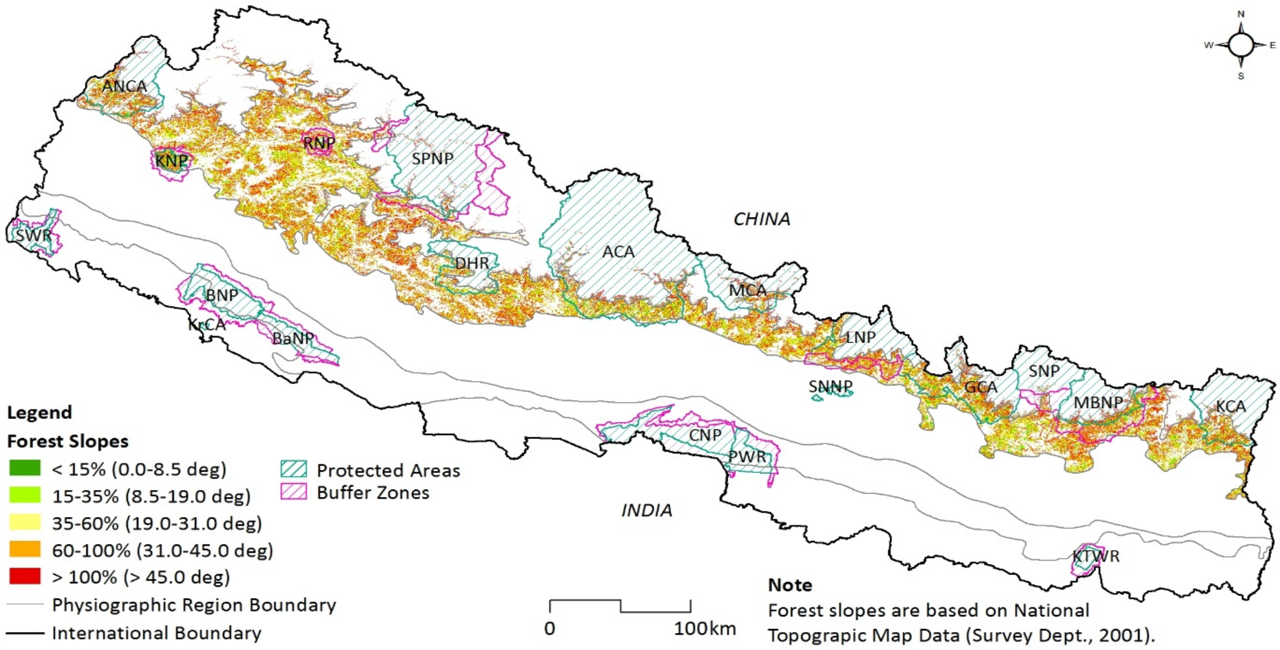

Figure 13: *Distribution of slope class in High Mountains and High Himal regions*

Forest Patch Size

The average size of forest patches in High Mountains is 44.50 ha. The total area occupied by the 19,419 patches less than 2 ha is 18,539 ha, or 1.46% of the total. In contrast, the three patches over 50,000 ha cover 189,609 ha, or 14.97% of the total. Similarly, the 8,536 forest patches sized 2–50 ha and the 403 patches sized 50–1,000 ha, comprised just 4.74% and 5.45% of the total, respectively (Figure 14).

Forest patch of at least 200 ha is generally considered suitable for scientific forest management (DoF, 2014). Number of smaller forest patches is by far highest in Mid-Western Development Region, where 49.28% of the forests under 200 ha is located. This is followed by Far-Western (26.35%), Eastern (12.06%), Western (9.5%) and Central (2.47%) Development Region. Central Development Region has the largest average patch size of 132 ha, followed by Western (73 ha), Eastern (67 ha), Mid-Western (40 ha) and Far-Western region (24 ha) in High Mountains (Annex 4a).

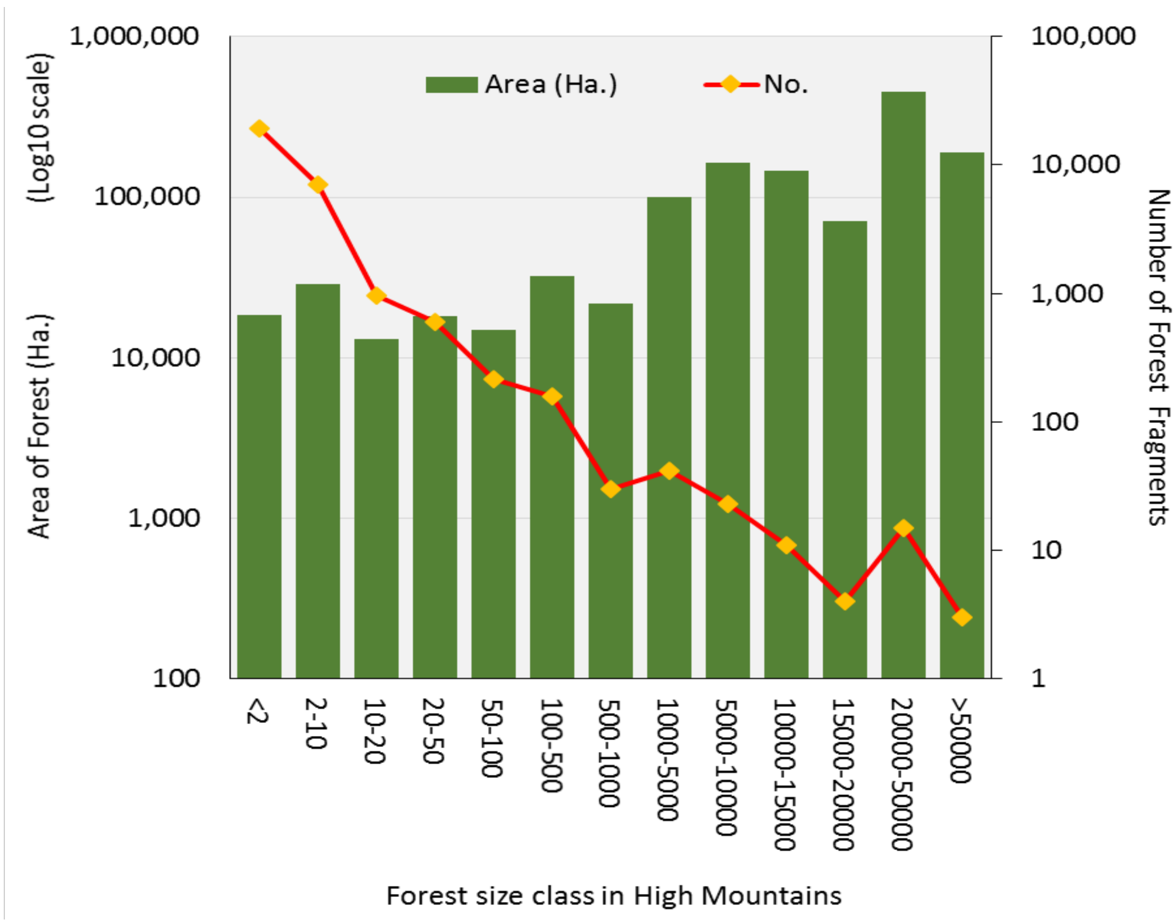

Figure 14: *Forest patch sizes in High Mountains*

In High Himal region, the average size of forest patches is 9.98 ha. The total area occupied by the 5,327 patches with less than 2 ha area is 5,271 ha, or 6.67% of the total area. Similarly, the 2,357 forest patches sized 2–50 ha and the 231 patches sized 50–1,000 ha, comprise 20.34% and 57.89% of the total, respectively. Ten patches sized 1,000–5,000 ha cover 15.10% (11,741ha) of the total area (Figure 15).

Mid-Western Development Region in High Himal has the highest number of smaller patches with 51.73% of the forests under 200 ha. This is followed by Far-Western (18.72%), Western (17.62%), Eastern (8.62%) and Central (3.30%) Development Region. Central Development Region has the largest average patch size (17.16 ha), followed by Eastern (15.84 ha), Far-Western (9.72 ha), Western (9.48 ha) and Mid-Western Region (9.79 ha) in High Himal (Annex 4b).

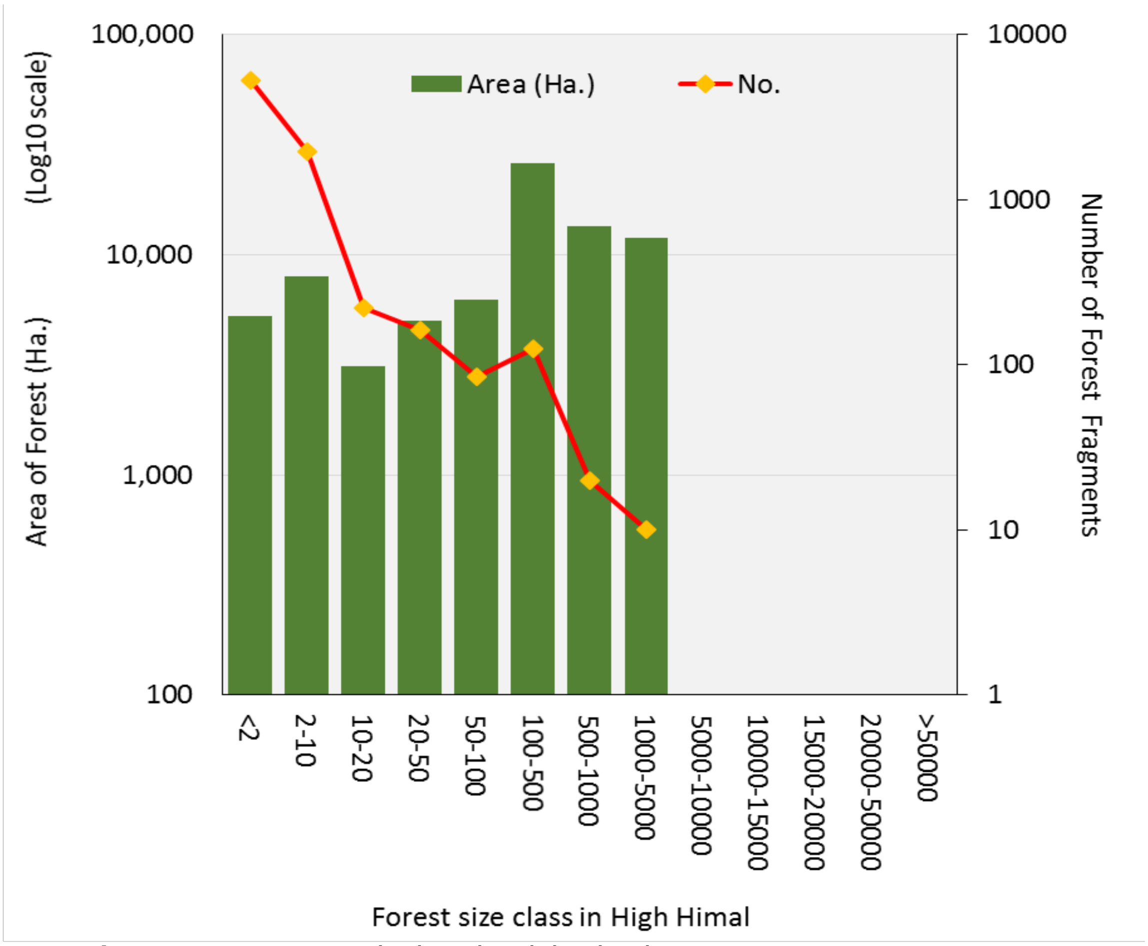

Figure 15: *Forest patch sizes in High Himal*

Accuracy Assessment

The combined results of High Mountains and High Himal forest cover mapping were compared with 317 independent ground samples from the national forest inventory. The land cover classes (Forest, OWL including shrub and Other Land) observed in the field were compared with the classified land cover classes (Forest, OWL including shrub and Other Land), revealing an overall accuracy of 66.56%, a Cohen's *Kappa* (κ) of 0.68, and a *kappa* standard error of 0.04 (Table 14).

Table 14: *Error matrix for forest cover map using independent ground verification samples*

Classified Class	Land Cover Class (Ground Truth)				User's Accuracy	Error of Commission
	Forest	OWL	Other Land	Total		
Forest	135	5	7	147	91.84%	8.16%
OWL	49	25	16	90	27.78%	72.22%
Other Land	24	5	51	80	63.75%	36.25%
Total	208	35	74	317		
Producer's Accuracy	64.90%	71.43%	68.92%			
Error of Omission	35.10%	28.57%	31.08%			
Overall Accuracy	66.56%					

Cohen's Kappa = 0.68. Kappa Standard Error = 0.04

The producer's accuracy for Forest, OWL and OL was 64.90%, 71.43% and 68.92%, respectively. An accuracy assessment of shrub classification was excluded for three reasons: the number of sample plots was insufficient for conducting an unbiased accuracy assessment, shrubs were classified using ground observation plots, and the classification of shrubs was challenging given the nature of the remote sensing material used and the limited ground observation data.

5.2 Forest Inventory

Number of Stems

Number of Stems (DBH ≥5 cm) per hectare

The combined total number of stems with DBH ≥5 cm is 2,116.44 million in High Mountains and High Himal region. Out of the total number of stems, 1,895.32 million (985.65/ha) is in Forest, 64.84 million (133.86/ha) in OWL and 156.28 million (130.56/ha) in Other Land (Table 15).

Table 15: *Number of stems/ha by land cover class*

Land cover class	No. of plots	No. of stems/ha
Forest	468	985.65
OWL	26	133.86
Other Land	130	130.56

In High Mountains and High Himal forests, co-dominant trees comprised the greatest number of stems per hectare (346.41), followed by dominant (299.90) and intermediate (229.83). There were about 35.20 standing dead trees per hectare. The trees removed annually appeared to be 1.46 per hectare (Table 16).

Table 16: *Number of stems according to crown class*

Tree category	Tree status	No. of stems/ha
Live trees	Dominant	299.90
	Co-dominant	346.41
	Intermediate	229.83
	Suppressed	43.06
	Understory	33.80
	Broken	32.65
Sub-total		**985.65**
Standing dead trees	Dead usable*	29.91
	Dead unusable	5.29
Sub-total		**35.20**
Removal		7.29**
Dead wood		Not Applicable

**Tree stems that can be used at least for firewood*

** A *five-year estimate*

The number of stems by forest type is shown in Table 17. The highest number of stems was in *Shorea robusta* forest (1,449/ha), followed by *Quercus* forest (1,337.97) and Upper Mixed Hardwood forest (1,107.65) (Table 17).

***Table 17**: Number of stems in forests by forest type*

Forest type	No. of plots	No. of stems/ha
Cupressus	4	598.65
Spruce	4	257.30
Abies	15	551.81
Quercus	46	1,337.97
Tsuga dumosa	3	405.77
UMH	271	1,107.65
Betula	12	297.77
Juniperus wallichiana	1	299.30
Pinus wallichiana	24	614.57
Shorea robusta	2	1,449.30
Cedrus	5	496.96
LMH	61	926.68
Pinus roxburghii	16	273.15
TMH	4	435.96
Total	**468**	**985.65**

In terms of the number of stems (≥5 cm DBH) per hectare, *Rhododendron* spp. was the dominant species (234.45/ha) followed by *Quercus* spp. (149.46/ha). The average weighted DBH of *Tsuga dumosa* was the largest (100.88 cm) followed by *Abies* spp. (68.68 cm). The average weighted height of *Tsuga dumosa* was greatest (28.79 m) followed by *Pinus wallichiana* (27.89 m) (Table 18).

***Table 18:** Characteristics of common tree species of forests*

Tree Species	No. of stem/ha	Weighted[1]	
		DBH (cm)	Height (m)
Rhododendron spp.	234.45	27.09	9.26
Quercus spp.	149.46	55.35	17.06
Abies spp.	30.15	68.68	23.32
Alnus spp.	18.34	47.18	21.28
Schima wallichii	17.34	27.58	13.40
Betula spp.	17.26	49.89	17.28
Castonapsis spp.	14.22	32.89	12.97
Pinus wallichiana	13.96	61.88	27.89
Tsuga dumosa	13.06	100.88	28.79
Acer spp.	12.24	54.58	17.34
Pinus roxburghii	7.93	43.56	21.78
Cedrus deodara	5.32	54.56	20.49
Other species	451.93		
Total	**985.65**		

[1] Weighted on the basis of basal area

Regarding the number of stems per hectare there were 27.96 mature stems (≥50 cm DBH), 53.18 stems with 30–50 cm DBH, 96.05 stems with 20–30 cm DBH, 349.32 stems with 10–20 cm DBH and 459.15 stems with 5–10 cm DBH. In the diameter classes of 5–10 cm, 10–20 cm and 20–30 cm, *Rhododendron* spp. comprised the greatest number of stems per hectare. In the diameter classes of 30–50 and ≥50 cm, *Quercus* spp. comprised the greatest number of stems per hectare (Table 19).

Table 19: *Number of stems/ha in forests by species and DBH classes*

Tree Species	DBH class (cm)					Total
	5–10	**10–20**	**20–30**	**30–50**	**≥50**	
Rhododendron spp.	108.82	93.23	22.35	8.42	1.63	234.45
Quercus spp.	61.71	52.80	16.57	10.03	8.35	149.46
Abies spp.	8.50	9.88	4.70	4.40	2.67	30.15
Alnus spp.	1.70	8.33	4.21	2.86	1.24	18.34
Schima wallichii	8.08	6.80	1.70	0.63	0.14	17.34
Betula spp.	4.68	5.45	2.43	3.29	1.42	17.26
Castanopsis spp.	5.10	5.57	2.18	1.11	0.26	14.22
Pinus wallichiana	2.98	4.89	2.23	2.32	1.55	13.96
Tsuga dumosa	7.23	2.66	0.42	0.61	2.14	13.06
Acer spp.	1.70	6.38	1.96	1.38	0.82	12.24
Pinus roxburghii	2.55	2.44	0.92	1.40	0.62	7.93
Cedrus deodara	2.55	1.70	0.37	0.39	0.31	5.32
Other species	243.55	149.20	36.02	16.33	6.83	451.93
Total	**459.15**	**349.32**	**96.05**	**53.18**	**27.96**	**985.65**

In terms of species and quality, the average number of stems per hectare comprised 123.18 high-quality sound trees (quality class 1), 214.89 sound trees (quality class 2), and 647.67 cull trees (quality class 3). *Quercus* spp. had the greatest number of stems per hectare in quality class 1 followed by *Abies* spp. In quality class 2 and 3, *Rhododendron* spp. had the greatest number of stems per hectare followed by *Quercus* spp. (Table 20).

Table 20: *Number of stems/ha in forests by species and quality class*

Tree Species	Number of stems/ha by quality class			Total	%
	Quality-1	**Quality-2**	**Quality-3**		
Rhododendron spp.	8.80	47.54	178.11	234.45	23.78
Quercus spp.	17.24	31.40	100.82	149.46	15.16
Abies spp.	16.23	7.68	6.25	30.15	3.06
Alnus spp.	10.07	3.78	4.49	18.34	1.86
Schima wallichii	3.09	3.27	10.99	17.34	1.76
Betula spp.	2.74	3.96	10.56	17.26	1.75
Castanopsis spp.	5.68	3.64	4.90	14.22	1.44

Pinus wallichiana	7.52	4.48	1.96	13.96	1.42
Tsuga dumosa	3.09	6.84	3.13	13.06	1.32
Acer spp.	2.68	2.45	7.11	12.24	1.24
Pinus roxburghii	3.05	0.39	4.49	7.93	0.80
Cedrus deodara	1.12	4.19	0.00	5.32	0.54
Other species	41.87	95.27	314.78	451.93	45.84
Total	**123.18**	**214.89**	**647.59**	**985.65**	**100.00**

Number of Stems (DBH <5 cm)

The number of seedlings (height <1.3 m) in High Mountains and High Himal forests was 2,399 per hectare. The average number of saplings (height ≥1.3 m and DBH <5 cm) per hectare was 831. *Rhododendron* spp. was the most numerous in both seedlings (301/ha) and saplings (122/ha). The next most numerous was *Quercus* spp. in both seedlings (292/ha) and saplings (74/ha) (Table 21).

Table 21: *Species-wise regeneration status per hectare*

Tree Species	**Seedlings (No./ha)**	**Saplings (No./ha)**	**Total (No./ha)**
Abies spp.	85	27	112
Acer spp.	37	26	63
Alnus spp.	26	12	38
Betula spp.	19	20	39
Castanopsis spp.	31	13	44
Cedrus deodara	16	3	19
Pinus roxburghii	23	14	37
Pinus wallichiana	64	16	80
Quercus spp.	292	74	366
Rhododendron spp.	301	122	423
Schima wallichii	25	12	37
Tsuga dumosa	33	7	40
Other species	1,447	483	1,927
Total	**2,399**	**831**	**3,230**

The species composition of regeneration in different forest types is given in Table 22.

Table 22: *Species composition of regeneration in different forest types*

Forest Type	Abies		Betula		Cedrus		Cupressus		LMH		Pr		Pw		Q		Spruce		TMH		UMH		Others	
Species	Saplings	Seedlings	Saplings	Seedlings	Saplings	Seedlings	Saplings	Seedlings	Saplings	Seedlings	Saplings	Seedlings	Saplings	Seedlings	Saplings	Seedlings	Saplings	Seedlings	Saplings	Seedlings	Saplings	Seedlings	Saplings	Seedlings
Abies spp.	318	597	166	199	0	0	0	0	0	0	0	0	33	91	4	160	0	0	0	0	15	65	133	199
Acer spp.	0	146	0	0	0	0	0	0	7	59	0	0	0	0	22	43	0	0	0	0	40	34	0	99
Alnus spp.	0	0	0	0	0	0	0	0	46	68	62	0	0	0	0	0	0	0	0	0	7	29	0	0
Betula spp.	0	0	514	66	0	0	0	0	0	0	0	0	17	66	0	0	0	0	0	0	10	23	0	0
Castanopsis spp.	0	0	0	0	0	0	0	0	46	124	0	0	0	0	9	9	0	0	0	0	11	24	0	0
Cedrus deodara	0	0	0	0	318	1472	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinus roxburghii	0	0	0	0	0	0	0	0	10	7	336	560	0	0	0	0	0	0	0	0	1	6	0	0
Pinus wallichiana	0	0	0	50	119	239	0	50	0	0	0	0	191	895	0	35	0	50	0	0	9	18	0	0
Quercus spp.	0	464	133	149	0	0	1243	2089	13	137	0	37	17	182	324	839	0	0	0	0	44	250	0	0
Rhododendron spp.	0	40	0	0	0	0	348	398	13	160	25	87	99	141	91	134	0	0	0	0	168	428	365	332
Schima wallichii	0	0	0	0	0	0	0	0	72	183	62	0	0	0	0	9	0	0	0	0	1	1	0	0
Tsuga dumosa	0	40	0	0	0	0	0	0	0	0	0	0	0	182	0	13	0	199	0	0	3	33	431	0
All others	305	1035	50	0	0	0	149	945	290	1259	137	696	356	680	519	2880	199	895	298	1741	610	1459	133	2288
Total	**623**	**2321**	**862**	**464**	**438**	**1711**	**1741**	**3482**	**496**	**1996**	**622**	**1380**	**713**	**2238**	**969**	**4122**	**199**	**1144**	**298**	**1741**	**921**	**2369**	**1061**	**2918**

Regeneration was the highest in *Cupressus* forests, followed by *Quercus* and Upper Mixed Hardwood (UMH). Regeneration in *Betula* forests was the lowest. The number of regeneration was the greatest in forests with the highest crown cover. The greatest number of regeneration (seedlings and saplings) were found in forest stand that were in the pole timber development stage (Table 23).

Table 23: *Regeneration status by forest type, crown cover and development status*

Forest type	No. of plots	Seedlings/ha	Sapling/ha	Total
Abies	15	2,321	623	2,944
Betula	12	464	862	1,326
Cedrus	5	1,711	438	2,149
Cupressus	4	3,482	1,741	5,222
LMH	61	1,996	496	2,492
Pinus roxburghii	16	1,380	622	2,002
Pinus wallichiana	24	2,238	713	2,951
Quercus	46	4,122	969	5,090
Spruce	4	1,144	199	1,343
TMH	4	1,741	298	2,039
UMH	271	2,369	921	3,290
All others	6	2,918	1,061	3,979
Total/Average	**468**	**2,399**	**831**	**3,230**
Crown cover				
<40%	83	1,970	537	2,507
40–69%	189	1,992	732	2,724
>70%	196	2,965	1,051	4,016
Total/Average	**468**	**2,399**	**831**	**3,230**
Development status				
Seedlings and saplings stand (<12.5 cm DBH)	15	849	464	1,313
Pole timber stand (<12.5–25.0 cm DBH)	129	2,885	1,006	3,891
Small saw timber stand (25.0–50.0 cm DBH)	170	2,303	857	3,160
Large saw timber stand (>50.0 cm DBH)	154	2,237	691	2,928
Total	**468**	**2,399**	**831**	**3,230**

Regeneration (Seedling and Sapling) by Management Regime

Total regeneration was the highest in Buffer Zone (5,156/ha) and the lowest in Public (*Parti*) land (133/ha). The highest number of seedlings (4,310/ha) was found in Buffer Zone whereas the lowest number (133/ha) in Public land. Regarding saplings, Protected Area had the highest number (1,447/ha) and there was no regeneration in Public land (Table 24).

Table 24: *Regeneration by forest management regime*

Forest management regime	No. of plots	Seedlings/ha	Saplings/ha	Total (no./ha)
Private forest	25	1,966	294	2,260
Government managed forest	197	2,167	702	2,869
Protected Area	29	2,257	1,447	3,704
Buffer Zone	12	4,310	846	5,156
Conservation Area	43	1,536	9,62	2,498
Community forest	159	2,902	941	3,842
Public land	3	133	0	133
Total	**468**	**2,399**	**831**	**3,230**

Regeneration (Seedling and Sapling) by Development Region

Seedling regeneration in High Mountains and High Himal forests was the highest in Eastern Development Region, followed by Central and Western Development Regions. Sapling regeneration was the highest in Central Development Region, followed by Far-Western and Western Development Regions. Mid-Western Development Region had the least number of seedlings and saplings per hectare (Table 25).

Table 25: *Status of regeneration in different Development Regions*

Development region	No. of plots	Seedlings/ha	Saplings/ha
Far-Western	80	2,096	833
Mid-Western	139	1,679	600
Western	96	2,607	756
Central	84	2,852	1,402
Eastern	69	3,336	701
Total	**468**	**2,399**	**831**

Basal Area

The basal area of stems (≥5 cm DBH) was 30.54 m^2/ha in Forest, 1.68 m^2/ha in OWL, and 2.51 m^2/ha in Other Land (Table 26).

Table 26: *Basal area per ha by land cover class*

Land cover class	No. of plots	Basal area (≥5 cm DBH) (m^2/ha)
Forest	468	30.54
OWL	26	1.68
Other Land	130	2.51

Out of the total basal area in High Mountains and High Himal forests, live trees represent 30.54 m^2/ha, about two-thirds of which was represented by dominant trees. The total basal areas of standing dead trees was 1.13 m^2/ha (Table 27).

Table 27: *Basal area per ha by tree status*

Tree category	**Tree status**	**Basal area (m^2/ha)**
Live trees	Dominant	19.31
	Co-dominant	6.87
	Intermediate	2.57
	Suppressed	0.50
	Understory	0.29
	Broken	1.00
Sub-total		**30.54**
Standing dead trees	Dead usable*	0.95
	Dead unusable	0.19
Sub-total		**1.13**
Removal		0.35**
Dead wood		Not Applicable

**Tree stems that can be used at least for firewood*
*** A five years estimate*

By forest type, *Cupresus* forests had the greatest basal area (58.96 m^2/ha), followed by Spruce (54.64 m^2/ha). Terai Mixed Hardwood (TMH) forest had the least basal area (12.23 m^2/ha) (Table 28).

Table 28: *Basal area (m^2/ha) in forests by forest type*

Forest type	**No. of plots**	**Basal area (m^2/ha)**
Cupressus	4	58.96
Spruce	4	54.64
Abies	15	41.90
Quercus	46	39.07
Tsuga dumosa	3	36.67
UMH	271	32.59
Betula	12	32.34
Juniperus wallichiana	1	27.00
Pinus wallichiana	24	25.27
Shorea robusta	2	21.17
Cedrus	5	20.89
LMH	61	16.94
Pinus roxburghii	16	13.79
TMH	4	12.23
Total	**468**	**30.54**

On the basis of diameter class, per hectare basal area was 2.05 m^2/ha in 5–10 cm, 5.61 m^2/ha in 10–20 cm, 4.46 m^2/ha in 20–30 cm, 6.05 m^2/ha in 30–50 cm and 12.38 m^2/ha in ≥50 cm. *Quercus* spp. had the largest basal area, approximately 22% of the total followed by *Rhododendron* spp. (15%) (Table 29).

Table 29: *Basal areas (m^2/ha) on forests by species and DBH class*

Tree Species	DBH Class (cm)					Total	%
	5–10	10–20	20–30	30–50	≥50		
Quercus spp.	0.29	0.86	0.77	1.17	3.54	6.63	21.70
Rhododendron spp.	0.50	1.49	1.02	0.91	0.50	4.42	14.47
Abies spp.	0.03	0.18	0.23	0.53	1.32	2.29	7.50
Tsuga dumosa	0.03	0.04	0.02	0.07	1.41	1.58	5.17
Pinus wallichiana	0.01	0.08	0.11	0.28	0.70	1.18	3.86
Alnus spp.	0.01	0.16	0.19	0.34	0.47	1.17	3.83
Betula spp.	0.02	0.09	0.12	0.39	0.50	1.12	3.67
Acer spp.	0.01	0.11	0.09	0.16	0.34	0.70	2.29
Castanopsis spp.	0.02	0.10	0.10	0.13	0.08	0.43	1.41
Pinus roxburghii	0.01	0.04	0.05	0.16	0.17	0.43	1.41
Schima wallichii	0.04	0.11	0.08	0.07	0.04	0.34	1.11
Cedrus deodara	0.02	0.03	0.02	0.05	0.12	0.23	0.75
Other species	1.06	2.34	1.66	1.80	3.17	10.03	32.83
Total	**2.05**	**5.61**	**4.46**	**6.05**	**12.38**	**30.54**	**100.00**

Volume

In High Mountains and High Himal, the total stem volume with DBH ≥5 cm was 467.96 million m^3. Out of total stem volume, 446.92 million m^3 (232.42 m^3/ha) were in Forest, 3.93 million m^3 (8.11 m^3/ha) in OWL and 17.10 million m^3 (14.29 m^3/ha) in Other Land (Table 30). The standard error of the mean stem volume in percent was 6.76% on Forest.

Table 30: *Stem volume per ha by land cover class*

Land cover class	No. of plots	Stem vol (m^3/ha)	Standard error of mean stem volume (%)
Forest	468	232.42	6.76
OWL	26	8.11	36.57
Other Land	130	14.29	18.47

The total stem volume of live trees in High Mountains and High Himal forests was 232.42 m^3/ha. The total stem volume of standing dead trees and dead wood was 6.99 m^3/ha and 18.32 m^3/ha, respectively (Table 31). The stem volume of removed trees was estimated to be 0.60 m^3/ha/year.

***Table 31**: Stem volume per ha by tree status*

Tree category	Tree status	Tree stem vol. (m^3/ha)
Live trees	Dominant	170.33
	Co-dominant	40.42
	Intermediate	12.55
	Suppressed	2.72
	Understory	1.45
	Broken	4.95
Sub-total		**232.42**
Standing dead trees	Dead usable*	5.91
	Dead unusable	1.09
Sub-total		**6.99**
Removal		2.98**
Dead wood		18.32

**Tree stems that can be used at least for firewood*

** A five-year estimate

By forest type, *Cupressus* forest had the greatest stem volume (656.67 m^3/ha) followed by Spruce forests (651.81 m^3/ha). TMH forest had the least stem volume (73.16 m^3/ha) (Table 32).

***Table 32**: Stem volume of live trees by forest type*

Forest type	No. of plots	Stem volume (m^3/ha)
Cupressus	4	656.67
Spruce	4	651.81
Abies	15	456.21
Tsuga dumosa	3	384.45
Betula	12	297.93
Quercus	46	296.17
Juniperus wallichiana	1	285.22
UMH	271	230.17
Pinus wallichiana	24	228.54
Cedrus	5	170.52
Shorea robusta	2	142.50
Pinus roxburghii	16	137.17
LMH	61	107.77
TMH	4	73.16
Total	**468**	**232.42**

On the basis of DBH class, the stem volume was 7.18 m^3/ha in 5–10 cm, 26.63 m^3/ha in 10–20 cm, 27.40 m^3/ha in 20–30 cm, 46.28 m^3/ha in 30–50 cm, and 124.94 m^3/ha in ≥50 cm. *Quercus* spp. had the highest stem volume, 24.43% of the total followed by *Abies* spp. with 10.15% and *Rhododendron* spp. with 8.99% (Table 33).

Table 33: *Stem volume (m^3/ha) by species and DBH class*

Tree Species	DBH Class (cm)					Total	%
	5–10	**10–20**	**20–30**	**30–50**	**≥50**		
Quercus spp.	0.92	3.84	5.02	9.78	37.22	56.79	24.43
Abies spp.	0.11	1.13	1.92	5.54	14.87	23.58	10.15
Rhododendron spp.	1.69	6.35	5.36	4.82	2.67	20.90	8.99
Tsuga dumosa	0.10	0.21	0.16	0.62	16.76	17.86	7.68
Pinus wallichiana	0.05	0.47	0.74	2.66	9.93	13.85	5.96
Alnus spp.	0.04	1.16	1.78	3.41	5.11	11.49	4.94
Betula spp.	0.07	0.49	0.72	2.88	3.96	8.12	3.49
Acer spp.	0.03	0.55	0.56	1.21	2.69	5.03	2.16
Pinus roxburghii	0.03	0.19	0.32	1.65	2.39	4.58	1.97
Castanopsis spp.	0.09	0.53	0.59	0.86	0.55	2.61	1.12
Schima wallichii	0.12	0.53	0.50	0.51	0.33	1.99	0.86
Cedrus deodara	0.06	0.13	0.12	0.37	1.20	1.88	0.81
All others	3.87	11.05	9.61	11.95	27.27	63.75	27.43
Total	**7.18**	**26.63**	**27.40**	**46.28**	**124.94**	**232.42**	**100.00**

In terms of quality class, the stem volumes of high-quality sound trees (quality class 1), sound trees (quality class 2) and cull trees (quality class 3) were 136.63 m^3/ha, 43.87 m^3/ha and 51.92 m^3/ha, respectively. *Quercus* spp. comprised the major proportion (56.79 m^3/ha, or 24.43%) followed by *Abies* spp. (23.58 m^3/ha, or 10.15%) (Table 34).

Table 34: *Stem volume by species and quality class*

Tree Species	Stem volume (m^3/ha)				%
	Quality-1	**Quality-2**	**Quality-3**	**Total**	
Quercus spp.	31.11	12.74	12.94	56.79	24.43
Abies spp.	20.76	1.76	1.06	23.58	10.15
Rhododendron spp.	2.51	6.95	11.44	20.90	8.99
Tsuga dumosa	16.68	0.30	0.88	17.86	7.68
Pinus wallichiana	13.25	0.48	0.12	13.85	5.96
Alnus spp.	9.19	1.38	0.92	11.49	4.94
Betula spp.	3.26	2.82	2.03	8.12	3.49
Acer spp.	3.51	0.42	1.10	5.03	2.16

Pinus roxburghii	4.05	0.22	0.31	4.58	1.97
Castanopsis spp.	1.05	1.03	0.53	2.61	1.12
Schima wallichii	0.87	0.63	0.49	1.99	0.86
Cedrus deodara	1.61	0.27	0.00	1.88	0.81
Other species	28.77	14.88	20.10	63.75	27.43
Total	**136.63**	**43.87**	**51.92**	**232.42**	**100.00**

The largest proportion of the total stem volume without bark for both 10 cm top and 20 cm top diameters was comprised by high-quality sound trees followed by sound trees (Table 35).

Table 35: *Stem volume, basal area, number of stems by quality class*

Quality class	**Stems (no./ha)**	**Basal area (m^2/ha)**	**Stem vol. (m^3/ha)**
High-quality sound tree	123.18	13.73	136.63
Sound tree	214.89	6.76	43.87
Cull tree	647.59	10.05	51.92
Total	**985.65**	**30.54**	**232.42**

Consideration of size classes revealed that the proportion of small trees was higher than that of large ones. This fact indicated that High Mountains and High Himal forests were characterised by normal size class distribution for natural forests (Figure 16).

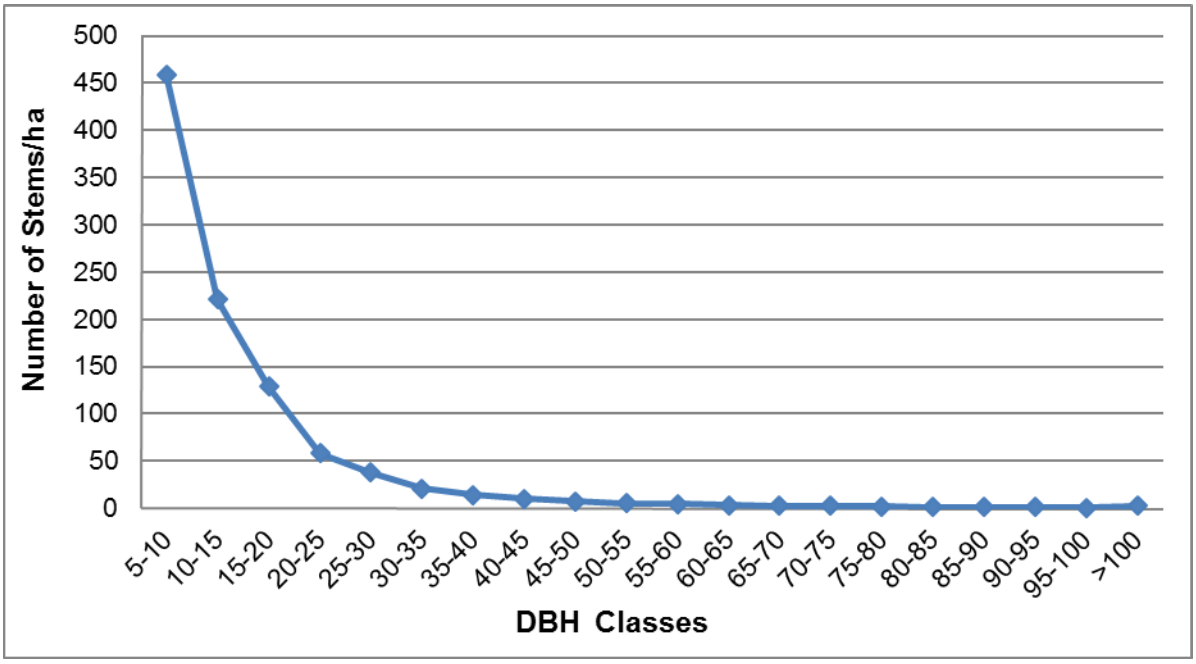

Figure 16: *Number of stems by DBH classes*

High-quality sound trees (quality 1) comprised the largest proportion of stem volume in the DBH class >50 cm, followed by 30–50 cm. (Figure 17).

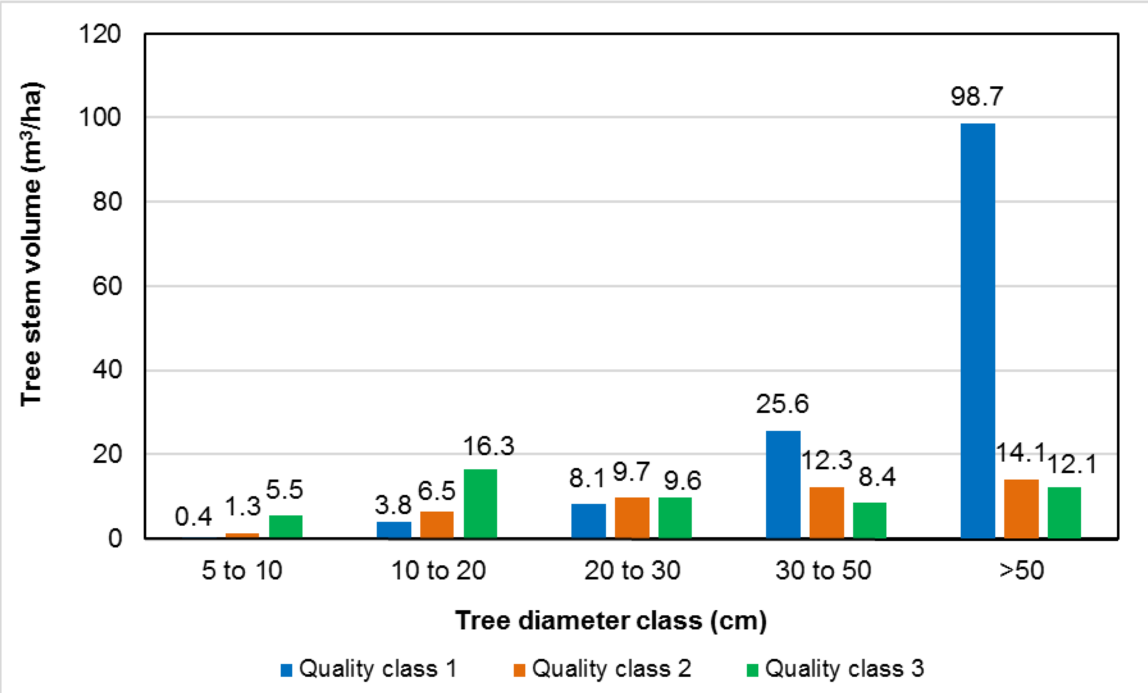

Figure 17: *Distribution of stem volume by quality class and tree size*

Biomass

The total air-dried biomass of live trees with a diameter ≥5 cm was 561.56 million tonnes in High Mountains and High Himal. Out of the total biomass, 538.12 million tonnes (279.85 t/ha) was in Forest, 5.84 million tonnes (12.05 t/ha) in OWL and 17.61 million tonnes (14.71 t/ha) in Other Land (Table 36).

Table 36: *Tree component-wise biomass per ha by land cover class*

Land cover class	No. of plots	Tree component	Air-dried biomass (≥5 cm DBH) (t/ha)
Forest	468	Stem	150.53
		Branch	105.17
		Foliage	24.15
		Total	**279.85**
OWL	26	Stem	5.69
		Branch	5.45
		Foliage	0.92
		Total	**12.05**
Other Land	130	Stem	8.65
		Branch	5.18
		Foliage	0.88
		Total	**14.71**

In Forest, the above-ground air-dried biomass of live trees was 279.85 t/ha and the below-ground biomass was 69.96 t/ha. The above-ground biomass and below-ground biomass of dead standing trees were 4.10 t/ha and 1.03 t/ha, respectively. The biomass of dead wood was 12.64 t/ha. In total, air-dried biomass of tree component including dead wood in Forest was 367.57 t/ha; and its oven-dried biomass was 334.16 t/ha (Table 37).

Table 37*: Above- and below-ground biomass in Forests (>5 cm DBH/diameter)*

I. Live trees (>5 cm DBH)	Biomass Components	Air-dried biomass (t/ha)
Above-ground	Stem	150.53
	Branch	105.17
	Foliage	24.15
Below-ground		69.96
II. Dead standing trees (>5 cm diameter)		
Above-ground	Stem	4.10
	Branch	0.00
	Foliage	0.00
Below-ground		1.03
III. Dead wood		

Above-ground	Stem	13.35
Total above-ground biomass		296.30
Total below-ground biomass		70.99
Total air-dried biomass		367.29
Total oven-dried biomass		333.90

By forest type, *Cupressus* forests had the greatest live tress biomass (1,109.47 t/ha), followed by Spruce forests (656.50 t/ha). TMH forests had the least total biomass (74.30 t/ha) (Table 38).

Table 38: *Total above-ground biomass in forests by forest type*

Forest type	No. of plots	Total biomass (air-dried, t/ha)
Cupressus	4	1,109.47
Spruce	4	656.50
Quercus	46	481.16
Betula	12	380.83
Abies	15	376.40
Tsuga dumosa	3	314.05
UMH	271	278.20
Juniperus wallichiana	1	270.84
Pinus wallichiana	24	197.75
Shorea robusta	2	154.42
Cedrus	5	143.59
Pinus roxburghii	16	127.47
LMH	61	112.13
TMH	4	74.30
Total	**468**	**279.85**

The biomass of stems, branches and foliage in Forest was approximately 150.53 t/ha, 105.17 t/ha, and 24.16 t/ha, respectively. *Quercus* spp. had the greatest stem, branch and foliage biomass. Overall, *Quercus* spp. had the highest biomass followed by *Rhododendron* spp. (Table 40).

Table 39: *Air-dried biomass by species and tree component (t/ha)*

Tree Species	Air-dried tree component biomass (t/ha)			
	Stem	Branch	Foliage	Total
Quercus spp.	48.84	48.44	10.21	107.49
Rhododendron spp.	13.38	10.09	3.33	26.80
Abies spp.	11.32	4.17	1.50	16.98
Betula spp.	5.68	5.86	1.06	12.60
Tsuga dumosa	8.04	2.88	0.91	11.82
Alnus spp.	4.48	5.65	0.41	10.54
Pinus wallichiana	5.54	2.49	1.16	9.19
Acer spp.	3.22	3.31	0.60	7.14

Pinus roxburghii	2.97	0.79	0.14	3.90
Castanopsis spp.	1.93	1.62	0.09	3.65
Schima wallichii	1.37	0.45	0.06	1.89
Cedrus deodara	1.05	0.39	0.14	1.59
Other species	42.70	19.03	4.52	66.25
Total	**150.53**	**105.17**	**24.16**	**279.85**

Forest Status with Different Canopy Closure by Forest Management Regime

The highest proportion (72.41%) of forest stand was found to be well stocked (>70%) in Protected Area, followed by Buffer Zone (58.33%) and Community forest (44.65%). Community forest and Government managed forest had almost similar forest stand under all three canopy closure classes (Table 40).

Table 40: *Proportions of forest stands with different classes of crown cover by forest management regime*

Forest management regime	Proportion of forest canopy closure		
	Poorly stocked (10–40%)	Moderately stocked (40–70%)	Well stocked (>70%)
Private Forest	36.00	56.00	8.00
Government Managed Forest	18.27	40.10	41.62
Protected Area	3.45	24.14	72.41
Buffer Zone	0.00	41.67	58.33
Conservation Area	23.26	46.51	30.23
Community Forest	15.72	39.62	44.65
Public Land	66.67	33.33	0.00

5.3 Soils of High Mountains and High Himal Forests

Soil, Litter and Woody Debris

Soil sample data were available from 310 plots, belonging to 140 clusters. The organic layer was mostly raw humus (43%) or humus (22%), and the layer was totally missing in 27% of soil profiles. Mull (1%) and peat (2%) soils were rare. Organic layer, when present, was thinner than 10 cm in 88% of profiles. Thickness from 10 to 30 cm was found evenly in the rest of the profiles.

The forest type with high organic carbon concentration (OC%) and organic carbon stock in the top 30 cm layer was *Abies* (Table 41). Similar high stocks were found in *UMH*, *Quercus* and Spruce forests, but the limited number of clusters representing those forest types results in high uncertainties. Still, the average SOC stock values can be considered to indicate high organic content in soil, in spite of the relative uncertainty caused by the calculations required by cluster sampling.

***Table 41**: Soil characteristics, litter and wood debris per hectare and number of clusters with soil data by forest types. The notation (-) means that standard error cannot be calculated with n=1.*

Forest type	**Bulk density of fine fraction**	**SOC (%)**	**Stonines s (%)**	**SOC, t/ha (Standard error)**	**Litter and woody debris (t/ha)**	**No. of clusters with soil data**
Abies	0.74	6.64	12.22	128.29 (241.14)	1.26	7
Betula	0.79	5.39	4.05	106.10 (277,74)	0.98	3
Cedrus deodara	1.06	3.16	13.75	92.70 (-)	1.55	1
Cupressus torulosa	0.80	4.65	59.00	97.92 (436.59)	0.41	2
Juniperus wallichiana	0.51	7.45	2.25	115.82 (-)	0.51	1
LMH	0.81	4.08	4.81	88.36 (36.19)	1.74	16
Pinus roxburghii	1.23	2.68	8.08	90.17 (242.99)	1.69	4
Pinus wallichiana	0.89	4.30	11.56	98.77 (104.93)	1.12	8
Quercus	0.88	4.83	8.65	121.21 (90.18)	1.39	14
Shorea robusta	1.19	2.32	8.13	82.65 (-)	6.44	1
Shrub	1.02	4.02	9.36	106.37 (68.89)	0.34	5
Spruce	0.57	7.61	18.75	119.16 (146.37)	1.04	2
Tsuga dumosa	0.78	4.68	9.13	99.83 (682.54)	0.86	2
Terai Mixed Hardwood	0.90	1.39	2.25	34.30 (-)	1.21	1
Upper Mixed Hardwood	0.73	6.19	9.61	121.72 (6.67)	1.46	73
Total	**0.79**	**5.47**	**9.98**	**114.03 (3.12)**	**1.44**	**140**

The overall average organic carbon stock in the 0–30 cm topsoil was estimated as 114.03 t/ha i.e. more than double the value for Middle Mountains forests (DFRS, 2015). The average carbon stock in litter and debris was 1.44 t/ha. Range of SOC stock was from 32 t/ha to 267 t/ha, while the median was close to the average, 111 t/ha, indicating that both the lowest and the highest carbon contents in forest soils were rare. While altitude explained a considerable amount of variation in SOC stocks in Middle Mountains physiographic region, in High Mountains and High Himal, that variation did not clearly follow altitude gradient. The highest average SOC stock was found in Far-Western (128.06 t/ha) followed by Eastern Development Region (127.91 t/ha) (Table 42).

Table 42: *Soil organic carbon, litter and debris by Development Region*

Development Region	SOC (SE) t/ha	Litter + Woody Debris (SE) t/ha	Number of Clusters with Soil Carbon Data	OC in 0–30 cm + Litter and Woody Debris, t/ha
Eastern	127.91 (54.06)	1.23 (0.0156)	21	124.03
Central	117.29 (27.67)	0.95 (0.0057)	18	117.86
Western	100.60 (22.01)	2.34 (0.0930)	22	102.65
Mid-Western	107.52 (16.43)	1.58 (0.0423)	35	108.16
Far-Western	128.06 (50.58)	0.99 (0.1556)	19	125.90

In high altitudes, the relative role of soil carbon in the total carbon pool is greater than in low altitudes. Biomass carbon stock in the mountain community forests, as reported by Pandey *et al.* (2014), was 107 t/ha, which is less than the estimate of FRA. The importance of SOC in the total carbon pool should be noted e.g. in monitoring the REDD+ projects. At lower physiographic regions, positive correlation of SOC with forest stand development status (FRA, 2014c) may indicate rapid loss of SOC after harvesting, but also reasonably fast recovery of SOC in the mountain forest ecosystems.

Only 13 forest stands out of 296, where soil analyses were available, represented the seedlings/saplings development status, meaning that the rest of the stands were more mature. Small or large saw timber stands covered almost 70% of stands. The similarity of SOC stocks between High Mountains and High Himal and among all administrative regions may reflect the overall mature status of forests, and a low-to-moderate human intervention.

5.4 Carbon Stock in High Mountains and High Himal Forests

The total carbon stock in High Mountains and High Himal forests was estimated to be 523.81 million tonnes (272.40 t/ha). Of the total carbon pool in the Forest, tree component contributed 57.61%; litter and debris contributed 0.53%; and soil contributed 41.86% (Table 43).

Table 43: *Carbon pool in High Mountains and High Himal forests*

By tree component	
Oven-dried biomass	333.90
Carbon (t/ha)	156.93
Total Carbon in tonnes	301,767,878
Total Carbon in tree component (million tonnes)	301.77
By litter and Debris	
Carbon t/ha	1.44
Total Carbon in tonnes	2,768,989
Total Carbon in litter and debris component (million tonnes)	2.77
By soil	
Carbon t/ha	114.03
Total Carbon in tonnes	219,269,313
Total Carbon in soil component (million tonnes)	219.27
Total	
Carbon (t/ha)	272.40
Total Carbon in tonnes	523,806,180
Total Carbon in High Mountains and High Himal Forests (million tonnes)	**523.81**

5.5 Forest Biodiversity

Tree Species Diversity

Altogether 275 tree species belonging to 157 genera and 79 families were recorded in the sample plots in High Mountains and High Himal physiographic regions. This figure constitutes about 40% of total tree species in Nepal reported by Press *et al.* (2000). Rosaceae (7 genera and 22 species) was the largest family followed by Lauraceae (7 genera and 19 species), the second largest. In terms of genera, *Ficus*, the largest genus, comprised 11 species, and *Quercus, Sorbus* and *Acer*, the second largest, each comprised 7 species (Annex 5). Tree data was compositional and had a gradient length (β-diversity, as determined by DCA analysis) of 14.10 SD units, a value indicating that the turnover of tree species from one sample plot to the next was very high. This indicates high tree species diversity.

The high Eigen values (CCA first axis = 61.39%; second axis = 19.77%) indicate that the heterogeneity of tree species was explained mostly by environmental variability. Most species are concentrated along the first axis towards the right side of the CCA graph, to the opposite of altitudinal gradient, indicating that the heterogeneity of tree species found at low altitudes is high. Some tree species, such as *Quercus semecarpifolia, Sorbus foliolosa, Rhododendron barbatum, Betula utilis* are positively correlated with altitude, indicating that they were found at higher altitudes. *Buchanania cochinchinensis, Engelhardia spicata*, *Diploknema butyracea*, *Schima wallichii, Alnus nepalensis, Castanopsis indica* showed strong negative correlations with altitude and were found on plots with litter-debris carbon and moderate slope. *Rhododendron barbatum, Rhododendron campanulatum* and *Acer acuminatum* favoured areas with high values of soil carbon and relatively wet spaces. Mountain aspect, slope and high bulk density of soil were negatively correlated with soil water and carbon pool (Figure 18).

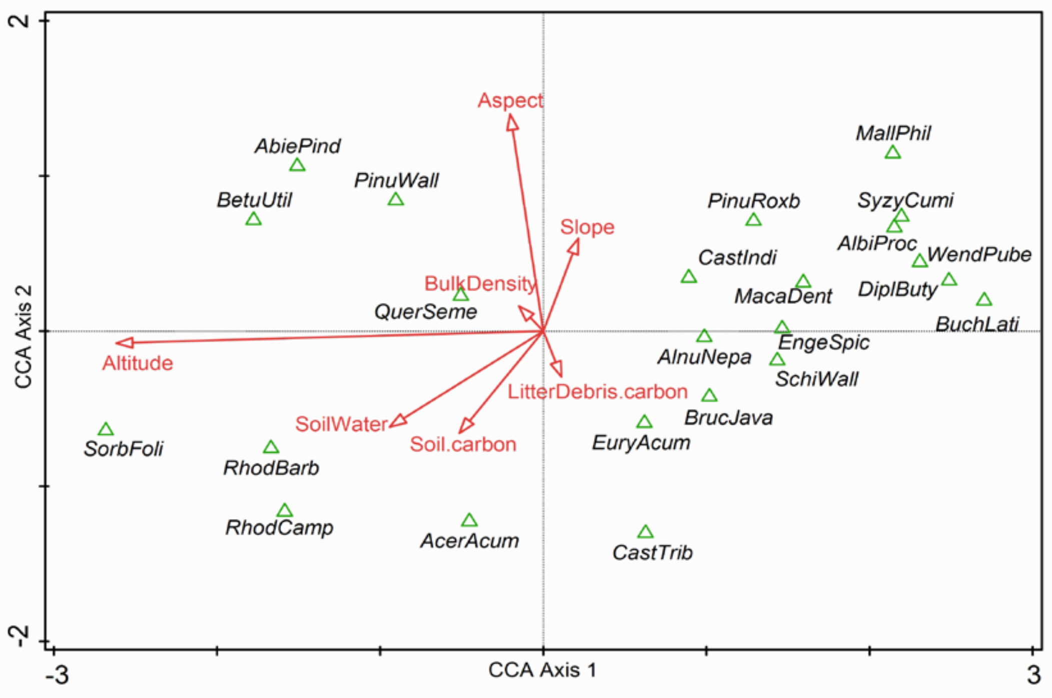

Figure 18: *Ordination plot of tree species with environment and soil variables*

Note: Predictor variables are represented by red arrows and tree species by green triangles. Tree species are listed by the first four letters of both the genus and the species. They include: AbiePind = *Abies pindrow,* AcerAcum = *Acer acuminatum*, AlbiProc = *Albizia procera*, AlnuNepa = *Alnus nepalensis,* BetuUtil = *Betula utilis,* BuchLati = *Buchanania cochinchinensis,* BrucJava = *Brucea javanica*, CastTrib = *Castanopsis tribuloides*, CastIndi = *Castanopsis indica,* DiplButy = *Diploknema butyracea*, EngeSpic = *Engelhardia spicata*, EuryAcum = *Eurya acuminate,* MallPhil = *Mallotus philippensis,* PinuRoxb = *Pinus roxburghii,* PinuWall = *Pinus wallichiana*, QuerSeme = *Quercus semecarpifolia,* RhodBbar = *Rhododendron barbatum,* RhodCamp = *Rhododendron campanulatum,* SchiWall = *Schima wallichii,* SorFoli = *Sorbus foliolosa,* SyzyCumi = *Syzygium* cumini and WendPube = *Wendlandia puberula*

Tree species diversity ranged from 1 to 23 per cluster and from 1 to 12 per plot in High Mountains forests. Similarly, tree species diversity ranged from 1 to 16 per cluster and from 1 to 10 per sample plot in High Himal region. Details about the abundance of tree species in High Mountains and High Himal region are presented in Annex 6.

Diversity Index

The value of the Shannon-Weaner diversity index ($\bar{H}$) for High Mountains region as a whole was 2.57. The indices for various forest types were 2.30 for UMH (n = 253); 1.72 for LMH (n = 60); 1.13 for for *Pinus roxburghii* (n = 16); 0.85 for *Abies* (n = 8); 1.09 for *Pinus wallichiana* (n = 13); 1.55 for *Quercus* spp. (n = 40); 0.77 for *Betula* spp. (n = 7); 1.56 for agriculture land (n = 51) and 1.37 for all other remaining types *(Cupressus,* Hemlock*, Betula,* Deodar and Spruce*)* (n = 28). Similarly, according to management regime, government managed forest (n = 172) had an index of 2.14; community forest (n = 159) had 2.12; private forest (n = 30) had 1.4 and the protected area system including Buffer Zone forest (n = 73) had 1.74.

Likewise, Shannon-Weaner diversity index ($\bar{H}$) for High Himal forests as a whole was 1.63. The indices for other major forests was 1.17 for UMH (n = 17); 0.85 for *Abies* (n = 8); 0.88 for *Pinus wallichiana* (n = 10); and 0.66 for all other remaining types (*Quercus*: n = 6*,* and *Betula:* n = 4).

Tree Species Occurrence

Rhododendron arboretum was the most numerous tree species in High Mountains and High Himal regions. It was found in 36% of the total sample plots. In order of descending existence, the other major tree species were, *Quercus semecarpifolia* (over 23%), *Lyonia ovalifolia* (16%) and *Alnus nepalensis* (13%) (Figure 19). Of the total 194 tree species from the sample plots of the High Mountains and High Himal, 36 (about 19%) was found only once in sample plots (Annex 6).

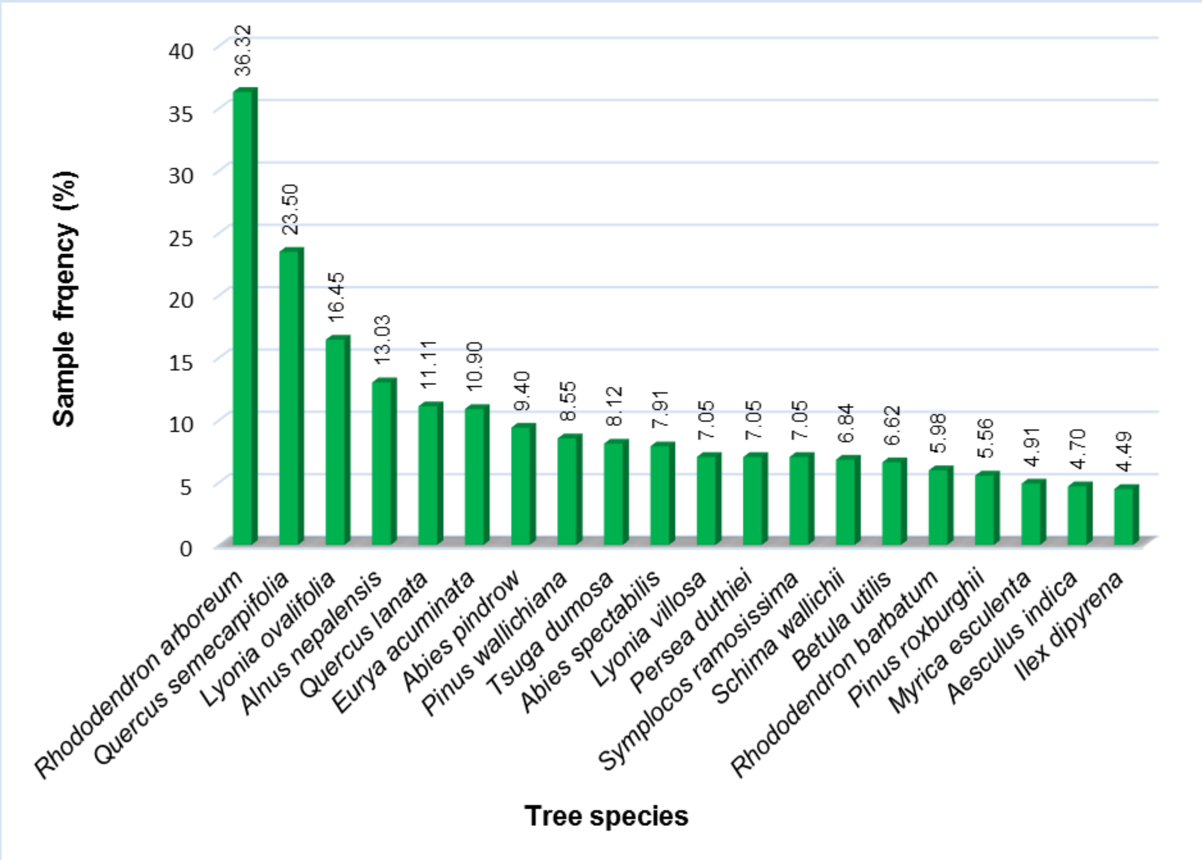

Figure 194: *Proportional distribution of major tree species present on the inventoried plots*

Non-Timber Forest Products

According to the social surveys, 755 different species of flora were used as NTFPs. Altogether, 227 species of trees belonging to 137 genera and 72 families; 159 species of shrubs belonging to 113 genera and 59 families; 277 species of herbs (including sedge and one fungi) belonging to 233 genera and 66 families; and 56 species of climbers belonging to 36 genera and 18 families were used as NTFPs. In addition, 36 species of ferns and fern-allies belonging to 19 genera and 14 families were also used as NTFPs. Among the floral community, Poaceae (30 genera and 41 species) and Fabaceae (52 genera and 13 species) were the largest families used as NTFPs. The most important and multi-purpose NTFP was *Diploknema butyracea*, which was used for 21 of 24 purposes inquired about. *Machilus duthiei* was the second most important species with 19 usages (Annex 7).

Thirteen percent of the NTFPs (492 species) were used as fodder, the most common usage. Among them, 37.60% were trees, 21.34% were shrubs, 33.13% were herbs, and 7.93% were climbers. Medicine was the next most common usage of NTFPs, comprising 11%. Of the NTFP species of the flora with medicinal usages, 31.52% were trees, 20.62% shrubs, 40.05% herbs and 7.82% climbers (Figure 20, Table 44).

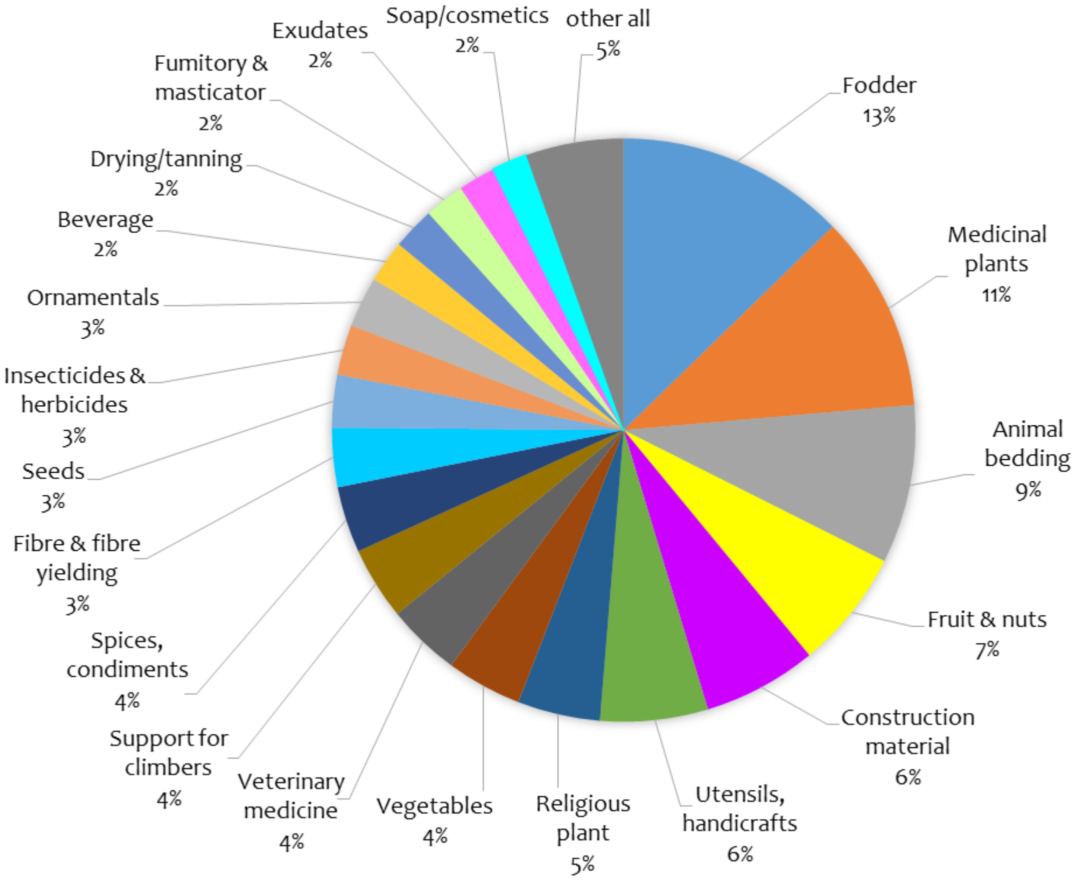

Figure 50: *Usage of plant NTFPs*

Usage purpose	Tree (%)	Shrub (%)	Herb/grass (%)	Climber (%)	Total number
Animal bedding	47.94	19.71	26.47	5.88	340
Beverage	58.24	19.78	17.58	4.40	91
Drying/tanning	60.44	23.08	13.19	3.30	91
Exudates	66.25	20.00	7.50	6.25	80
Fibre and fibre yielding	37.80	20.47	25.20	16.54	127
Fodder	37.60	21.34	33.13	7.93	492
Fruit and nuts	49.61	26.56	13.67	10.16	256
Fumitory and masticator materials	53.49	11.63	29.07	5.81	86
Insecticides and herbicides	42.59	21.30	32.41	3.70	108
Legumes or pulses	34.38	15.63	31.25	18.75	32
Medicinal plants	31.52	20.62	40.05	7.82	422
Seeds	72.57	10.62	13.27	3.54	113
Soap/cosmetics	38.67	18.67	34.67	8.00	75
Spices, condiments and other flavourings	31.69	19.72	41.55	7.04	142
Starches and cellulose products	32.20	18.64	33.90	15.25	59
Vegetable oils and fats	49.25	22.39	17.91	10.45	67
Vegetables	19.75	14.20	58.02	8.02	162
Utensils, handicrafts	61.04	20.35	16.02	2.60	231
Construction material	56.97	16.80	20.90	5.33	244
Ornamentals	56.48	16.67	22.22	4.63	108
Biofuel	73.08	15.38	9.62	1.92	52
Support for climbers/*Thankro*	65.38	21.79	11.54	1.28	156
Veterinary medicine	36.08	20.25	34.18	9.49	158
Religious plant	50.85	15.82	25.99	7.34	177

Table 44: *Usage of Plant-NTFPs*

Animal Derivatives

Altogether 78 animal species (64 genera from 34 families) were reported as being used in the combined High Mountains and High Himal sampling sites. Of the total, 36 species were mammals, 38 birds and one each was insect, amphibian and reptile (Annex 7). According to the social survey, wild animals were mostly used as meat. Other common uses, in order of descending usage, were as living animals, hides, skins for trophies and for medicine purposes. Some animals were also used for religious purpose (Table 45).

Table 45: *Usage of animal derivatives*

Usage purpose	Mammal %	Bird %	Reptile %	Amphibian%	Insect %	Total
Living animal	52.38	47.62	0.00	0.00	0.00	**42**
Honey, bees wax	0.00	0.00	50.00	0.00	50.00	**2**
Bush meat	41.94	56.45	0.00	1.61	0.00	**62**
Other edible animal products	33.33	60.00	0.00	3.33	3.33	**30**
Hides, skins for trophies	72.22	25.00	2.78	0.00	0.00	**36**
Medicines from animals	61.29	29.03	3.23	3.23	3.23	**31**
Drying/tanning	100.00	0.00	0.00	0.00	0.00	**3**
Tools	90.91	9.09	0.00	0.00	0.00	**11**
Ornaments	52.63	47.37	0.00	0.00	0.00	**19**
Religious	53.57	39.29	3.57	3.57	0.00	**28**

5.6 Forest Disturbances

Among the 468 measured forested plots in High Mountains and High Himal, altogether 1,103 instances of forest disturbance were recorded; 15% had no impact, 37% had minor impact, 34% had medium impact, and 14% were considered to be major disturbances. Anthropogenic disturbances were much more frequently recorded than natural disturbances. Grazing (62%) and tree-cutting (35%) were the most commonly reported disturbances in forest (Table 46).

Table 46: *Records of forest disturbances in the forest*

Disturbance	Intensity				Total	% of occurrence
	Zero	Minor	Medium	Major		
Bush cutting	11	39	14	7	71	15.17
Encroachment	14	5	14	3	36	7.69
Forest fires	2	30	21	9	62	13.25
Grazing	35	93	121	42	291	62.18
Insect attack	0	1	2	0	3	0.64
Landslide	36	11	9	15	71	15.17
Lathra cutting	13	55	37	8	113	24.15
Litter collection	15	12	24	6	57	12.18
Lopping	11	42	44	21	118	25.21
Plant disease	0	1	0	0	1	0.21
Plant parasites	0	1	1	0	2	0.43
Resin tapping	9	3	3	2	17	3.63
Tree cutting	16	74	55	21	166	35.47
Wind, storm, hails	0	12	19	20	51	10.90
Other disturbance	2	24	13	5	44	9.40
Total	**164**	**403**	**377**	**159**	**1,103**	
Percentage	**14.87**	**36.54**	**34.18**	**14.42**	**100.00**	

The average number of categories of disturbance per plot was three, and maximum number of disturbance was eleven. Nearly 25% of the plots were found to be undisturbed (Figure 21).

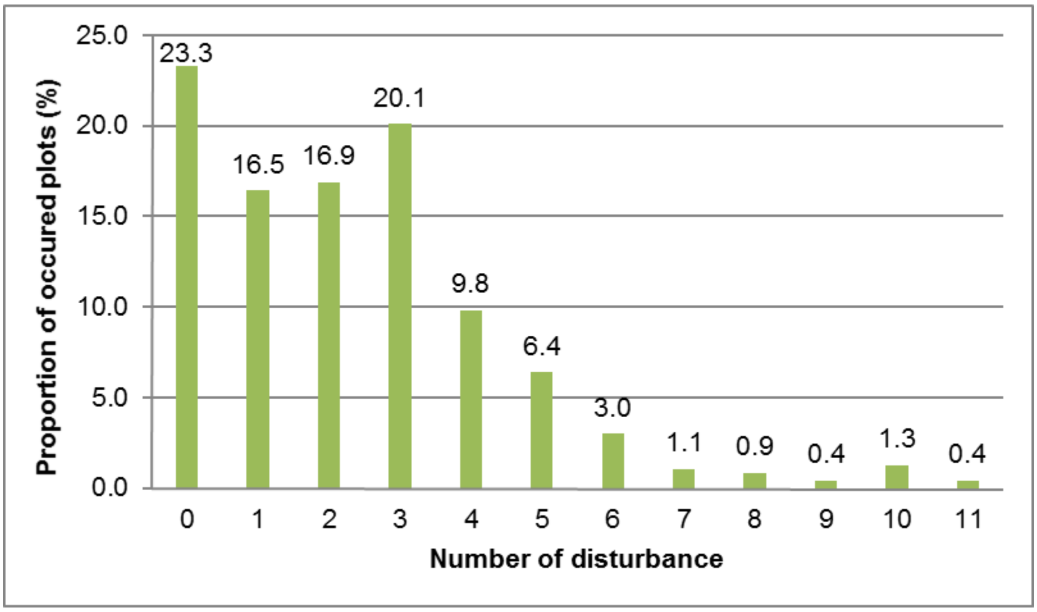

Figure 21: *Number of disturbances per plot*

Most disturbances were found in *Cupressus* forest and the least in *Cedrus* forest. Grazing was found to be the most common disturbance in all forest types in High Mountains and High Himal regions (Table 47).

Table 47: Proportion of forest disturbance in sample plots according to major forest type

Disturbance	Occurrence of disturbance (%) by forest type											
	Abies (15)	**Betula (12)**	**Cedrus (5)**	**Cupressus (4)**	**LMH (61)**	**Pr (16)**	**Pw (24)**	**Quercus (46)**	**Spruce (4)**	**TMH (4)**	**UMH (271)**	**Others (6)**
Bush cutting	13	0	0	100	20	6	25	9	0	100	14	0
Encroachment	7	0	0	100	18	0	4	15	0	0	4	0
Forest fires	40	8	20	100	15	6	25	4	75	25	10	17
Grazing	87	50	0	100	59	50	88	67	75	100	59	67
Insect attack	0	0	0	0	2	0	0	0	0	0	1	0
Landslide	7	0	0	100	20	6	4	7	0	0	18	0
Lathra cutting	40	33	20	100	28	6	42	15	0	75	22	0
Litter collection	13	0	0	100	13	25	25	4	0	25	11	0
Lopping	7	0	0	100	28	6	29	46	0	100	23	33
Plant disease	0	0	0	0	0	0	4	0	0	0	0	0
Plant parasites	0	0	0	0	0	0	0	0	0	0	1	0
Resin tapping	0	0	0	100	0	38	4	2	0	0	2	0
Tree cutting	40	8	60	100	18	13	38	48	50	50	37	50
Wind, storm, hails	33	50	0	0	8	0	25	11	25	0	8	17
Other disturbance	0	0	0	0	31	13	29	4	0	25	5	0

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7. ANNEXES

Annex 1: Diameter-Height models for High Mountains and High Himal Trees of Nepal

SN	species	Local_Name	Model	a	b	c	s.e	Ad. R^2
1	*Abies pindrow*	Gobre Salla, Thingre Salla	Näslund: h(d) = bh + d^2/(a + b d)^2	3.12	0.147		3.148	0.85
2	*Abies spectabilis*	Gobre Salla, Talis Patra	Näslund: h(d) = bh + d^2/(a + b d)^2	3.103	0.178		1.5	0.95
3	*Acer acuminatum*	Kanchiro	Wykoff: h(d) = bh + exp(a + b/(d + 1))	3.06	-10		2.975	0.75
4	*Alnus nepalensis*	Utis	Naslund [h(d) = bh + d^2/(a + b d)^2]	1.85	0.17		3.841	0.67
5	*Betula utilis*	Bhojpatra	Naslund [h(d) = bh + d^2/(a + b d)^2]	2.33	0.19		3.998	0.7
6	*Daphniphyllum himalense*	Rakchan	Naslund [h(d) = bh + d^2/(a + b d)^2]	1.69	0.22		3.076	0.51
7	*Eurya acuminata*	Jhingane	Näslund: h(d) = bh + d^2/(a + b d)^2	1.29	0.28		1.568	0.75
8	*Ilex dipyrena*	Seto Khasru	Naslund [h(d) = bh + d^2/(a + b d)^2]	4.33	0.19		2.606	0.79
9	*Lyonia ovalifolia*	Angeri	Naslund [h(d) = bh + d^2/(a + b d)^2]	1.728	0.283		1.351	0.86
10	*Lyonia villosa*	Angeri	Naslund [h(d) = bh + d^2/(a + b d)^2]	1.67	0.26		1.823	0.87
11	*Myrica esculenta*	Kaphal	Naslund [h(d) = bh + d^2/(a + b d)^2]	0.89	0.3		1.814	0.56
12	*Persea duthiei*	Mahilo kaulo, Kaulo	Curtis: h(d) = bh + a (d/(1 + d))^b	14.52	9.324		1.625	0.87
13	*Pinus roxburghii*	Khote sallo	Prodan [h(d) = bh + d^2/(a + bd + c d^2)]	6.31	1.754	0.0047	2.938	0.88
14	*Pinus wallichiana*	Gobre sallo	Power: h(d) = bh + a d^b	2	0.59		2.535	0.94
15	*Quercus floribunda*	Seto Khasru	Naslund [h(d) = bh + d^2/(a + b d)^2]	3.588	0.175		3.304	0.76
16	*Quercus lanata*	Thulo Banjh	Naslund [h(d) = bh + d^2/(a + b d)^2]	3.292	0.208		2.52	0.82
17	*Quercus semicarpifolia*	Khashru	Naslund [h(d) = bh + d^2/(a + b d)^2]	3.85	0.17		3.667	0.79
18	*Schima wallichi*	Chilaune	Naslund [h(d) = bh + d^2/(a + b d)^2]	2.282	0.189		3.48	0.66
19	*Symplocos ramosissima*	Kharane, Dabdabe	Naslund [h(d) = bh + d^2/(a + b d)^2]	1.64	0.24		2.377	0.71
20	*Tsuga dumosa*	Thingre Salla	Meyer: [h(d) = bh + a (1-exp(-b d))]	35.9	0.01		3.936	0.88
21	*Picea smithiana*	Jhule Salla	Naslund [h(d) = bh + d^2/(a + b d)^2]	2.882	0.137		3.249	0.9
22	Group 1		Näslund: h(d) = bh + d^2/(a + b d)^2	3.191	0.181		2.753	0.83
23	Group 2		Näslund: h(d) = bh + d^2/(a + b d)^2	2.56	0.18		1.299	0.91

24	Group 3		Näslund: h(d) = bh + d^2/(a + b d)^2	2.09	0.24		1.835	0.95
25	Group 4		Näslund: h(d) = bh + d^2/(a + b d)^2	3.17	0.18		3.022	0.81
26	Group 5		Näslund: h(d) = bh + d^2/(a + b d)^2	2.63	0.16		3.254	0.84
27	Group 6		Näslund: h(d) = bh + d^2/(a + b d)^2	3.3	0.19		0.962	0.98
28	Group 7		Näslund: h(d) = bh + d^2/(a + b d)^2	1.86	0.25		1.953	0.77
29	Group 8		Näslund: h(d) = bh + d^2/(a + b d)^2	2.413	0.213		2.762	0.8
30	Group 9		Naslund[h(d) = bh + d^2/(a + b d)^2]	2.464	0.198		3.127	0.8
31	Group 10		Naslund[h(d) = bh + d^2/(a + b d)^2]	2.064	0.22		2.892	0.79
32	Group 11		Naslund[h(d) = bh + d^2/(a + b d)^2]	2.499	0.203		2.908	0.79
33	Group 12		Naslund[h(d) = bh + d^2/(a + b d)^2]	2.173	0.262		2.249	0.77
34	Group 13		Naslund[h(d) = bh + d^2/(a + b d)^2]	2.15	0.258		2.222	0.74
35	Group 14		Naslund[h(d) = bh + d^2/(a + b d)^2]	2.27	0.26		2.159	0.73
36	Group 15		Naslund[h(d) = bh + d^2/(a + b d)^2]	2.304	0.212		3.703	0.64
37	Group 16		Naslund[h(d) = bh + d^2/(a + b d)^2]	2.19	0.28		1.179	0.81

Note:

Group 1

Quercus glauca (Sano Phalant), *Quercus glauca var.glauca* (Sano Phalant), *Quercus lamellosa* (Thulo Phalant), *Quercus leucotrichophora* (Tikhe Banjh), *Quercus oxyodon* (Phalant).

Group 2

Shorea robusta (Sal, Sakhuwa), *Trachycarpus takil* (Kumaon Palm), *Trachycarpus martianus* (Martius' fan palm), *Tectona grandis* (Teak), *Terminalia alata* (Asna), *Mesua ferrea* (Nageswar, Phalame)

Group 3

Sorbus thomsonii, *Sorbus lanata*, *Sorbus foliolosa*, *Sorbus cuspidata*, *Sorbus arachnoides*

Group 4

Toona serrata (Dallo), *Tonna ciliata* (Tooni), *Taxus baccata subsp. wallichiana* (Dhegre Salla), *Taxus baccata* (Dhegre Salla), *Syzygium jambos* (Jamun, Gulaf Jamun), *Syzygium cumini* (Jamun), *Symplocos* theifolia (Ghoge, Bakalpati), *Symplocos racemosa* (Lodh, Kholme), *Symplocos pyrifolia* (Kholme, Seti Kath), *Symplocos dryophila* (Sano Kharane), *Solanea dasycarpus* (Gobre)

Group 5

Saurauia roxburghii, *Saurauia napaulensis* (Gogan), *Saurauia fasciculata* (Sare Gogan), *Prunus cerasoides* (Paiyun), *Populus ciliata* (Lekh Pipal), *Polyalthia fragrans* (Labsi, Khutti), *Persea odoratissima* (Seto Kaulo), *Michelia doltsopa* (Rani Chanp), *Michelia champaca* (Aule Chanp), *Michelia cathcartii* (Kalo Chanp), *Malus baccata* (Koma), *Magnolia campbellii* (Chanp), *Madhuca latifolia* (Latimauwa), *Macaranga indica* (Mallata), *Macaranga denticulata* (Mallato)

Group 6

Lithocarpus grandifolius (Arkhaulo), *Lithocarpus pachyphylla* (Arkhaulo), *Lithocarpus elegans* (Arkhaulo), *Juniperus indica* (Dhupi), *Juniperus recurva* (Dhupi), *Dalbergia sissoo* (Sissoo), *Bombax ceiba* (Simal)

Group 7

Toricella tilifolia, *Streblus asper* (Khaksi, Bedulo), *Semecarpus anacardium* (Kage Bhalayo), Sapium insigne (Khirro), *Salix babylonica* (Bains), *Rhamnus purpureus*, *Pterospermum acerifolium* (Kanak Champa), *Prunus persica* (Aaru), Prunus napaulensis (Aarupate, Jangali Aru), *Phyllanthus emblica* (Amala), *Photinia integrifolia* (Gajphool), *Phoenix sylvestris* (Khajur), *Persea wallichii*, *Olea ferruginea* (Indian olive), *Myrica esculenta* (Kaphal), *Miliusa velutina* (Karyauta), *Michelia velutina* (Suna Chanp), *Meliosma dilleniifolia* (Kade Khabate)

Group 8

Ilex excelsa f.*hypotricha* (Puwale), *Litsea monopetala* (Kutmero), *Litsea doshia* (Paheli, Padhke Kath), *Litsea cubeba* (Siltimbur), *Litsea chartacea*, *Lindera pulcherrima* (Syalphusre), *Lindera melastomacea*, *Larix himalayaca* (Langtang Larch), *Larix griffithiana* (Lekh Sallo), *Lannea coromandelica* (Dabdabe), *Lagerstroemia parviflora* (Bot Dhaiyaro, Asare), *Hymenodictyon excelsum* (Karam), *Grewia subinaequalis* (Falsa), *Garuga pinnata* (Dabdabe), *Fraxinus floribunda* (Lankuri), *Ficus racemosa* (Dumri), *Ficus neriifolia* var.*neriifolia* (Dudhilo), *Ficus neriifolia* var.*nemoralis* (Dudhilo), *Ficus neriifolia* (Dudhilo), *Ficus lacor* (Kabhro), *Ficus hispida* (Kharseto), *Ficus glaberrima* (Pakhure), Ficus *auriculata* (Nimaro), *Ficus semicordata* (Khanyu)

Group 9

Ficus religiosa (Pipal), *Exbucklandia populnea* (Pipli), *Erythrina stricta* (Phaledo), *Erythrina arborescens* (Phaledo), *Englehardia spicata* var.*colebrookeana* (Mahuwa), *Englehardia spicata* (Mahuwa), *Diospyros malabarica* (Kalo Tendu), *Cupressus torulosa* (Agar Dhupi), *Cryptomeria japonica* (Dhupi), *Corylus ferox* (Lekh Katus), *Celtis australis* (Khari), *Cedrus deodara* (Devdar), *Carpinus viminea* (Himalayan Hornbeam), *Carpinus faginea* (Khadik), *Buchanania latifolia* (Piyari), *Bridelia retusa* (Gayo), *Bischofia javanica* (Kainjal), *Betula alnoides* (Saur), *Anogeissus latifolius* (Banjhi), *Alnus nitida* (Uttis)

Group 10

Xeromphis uliginosa (Pindar, Maidal), *Wendlandia* puberula (Ban Kanyau), *Uraria lagopus var.neglecta* (Nilo Tanki), *Rhus wallichii* (Thulo Bhalayo), *Rhus succedanea var.succedanea* (Rani Bhalayo), *Rhus javanica* (Bhakimlo), *Pyrus pashia* (Mayal), *Pyrularia edulis* (Amphi), *Mallotus philippensis* (Sindhure), *Machilus edulis* (Lepchche Kaulo), *Eriobotrya japonica* (Lokat), *Eriobotrya elliptica* (Maya), *Cinnamomum tamala* (Tejpat), *Cinnamomum glanduliferum* (Sinkauli), *Castanopsis tribuloides* (Musure katus), *Castanopsis lancifolia* (Aunle Katus), *Castanopsis hystrix* (Patale Katus), *Bauhinia variegate* (Seto Koiralo), *Bauhinia purpurea* (Rato Koiralo), *Bauhinia malabarica* (Tanki), *Albizia procera* (Seto Sirish), *Albizia chinensis* (Kalo Sirish), *Alangium chinense* (Timil), *Abies densa* (Gobre Salla)

Group 11

Salix disperma (Willow), *Prunus rufa* (Himalayan cherry), *Osmanthus fragrans* (Silinge), *Ligustrum confusum* (Kanike), *Leucoseptrum canum* (Ghurmis), *Juglans regia* (Okhar), *Ilex godajam* (Gurbe), *Ilex fragilis* (Thulo Kharane), *Ehretia laevis* (Datingal), *Desmodium oojenense*, (Sadan), *Daphniphyllum himalense* (Rakchan), *Daphniphyllum himalense* var.*chartaceum* (Rakchan), *Cocculus laurifolius* (Snailseed)

Group 12

Woodfordia fruticosa (Dhaiyaro), *Wendlandia coriacea*, *Viburnum nervosum* (Asara), *Viburnum erubescens var*., *erubescens* (Bajrang, Ganmane), *Viburnum erubescens* (Bajrang, Ghodakhari), *Viburnum cylindricum* (Gharghure, Ghodekhari), *Viburnum continifolium* (Ghodekhari, Bakal Pate), *Swida macrophylla*, Scurrula *parasitica* (Lisso, Ainjeru), *Sarcococca hookeriana* (Telparo), *Rosa sericea* (Tanso, Bhote, Gulaf), *Rhododendron cinnabarinum* (Sanu Chimal, Bulu Guras), *Punica granatum* (Anar, Darim)

Group 13

Macropanax dispermus (Charipila), *Justicia adhatoda* (Asuro, Kalo, Bhasak, Yasur), *Hippophae tibetana* (Serke), *Hippophae salicifolia* (Khurapu, Asuk), *Helixanthera ligustrina* (Lisso, Ainjeru), *Grewia optiva* (Bhimal, Bhebul), *Gaultheria fragrantissima* (Patpate, Dhasingare), *Euphorbia royleana* (Siundi), *Euonymus fimbriatus*, *Euonymus amygdalifolius*, *Elaeagnus parvifolia* (Guyanli, Kankol, Madilo), *Elaeagnus infundibularis* (Timru, Madilo, Goili, Guyali), *Dodecadeni grandiflora* (Nepali Dalchini), *Docynia indica* (Mehul, Passi), *Desmodium multiflorum* (Bakhre Ghas), *Debregeasia salicifolia*, *Cotoneaster frigidus* (Dar, Tusare), *Cotoneaster acuminatus* (Chhar), *Clerodendrum indicum* (Dhalke Phool), *Ceratostigma ulicinum* (Chinde, Bhargi, Angiyaha), *Camellia kissi* (Hibuwa, Chiya Pate), *Callicarpa microphylla* (Daikamala), *Boehmeria rugulosa* (Daar, Getha), *Berberis asiatica* (Chutro), *Berberis aristata* var. *floribunda* (Chutro), *Berberis aristata* (Chutro), *Berberis angulosa* (Chutre Kanda), *Benthamidia capitata* (Damaru), *Acacia pennata* (Aradi, Arare), *Pyracantha crenulata* (Ghangaru, Kath Gedi),

Group 14

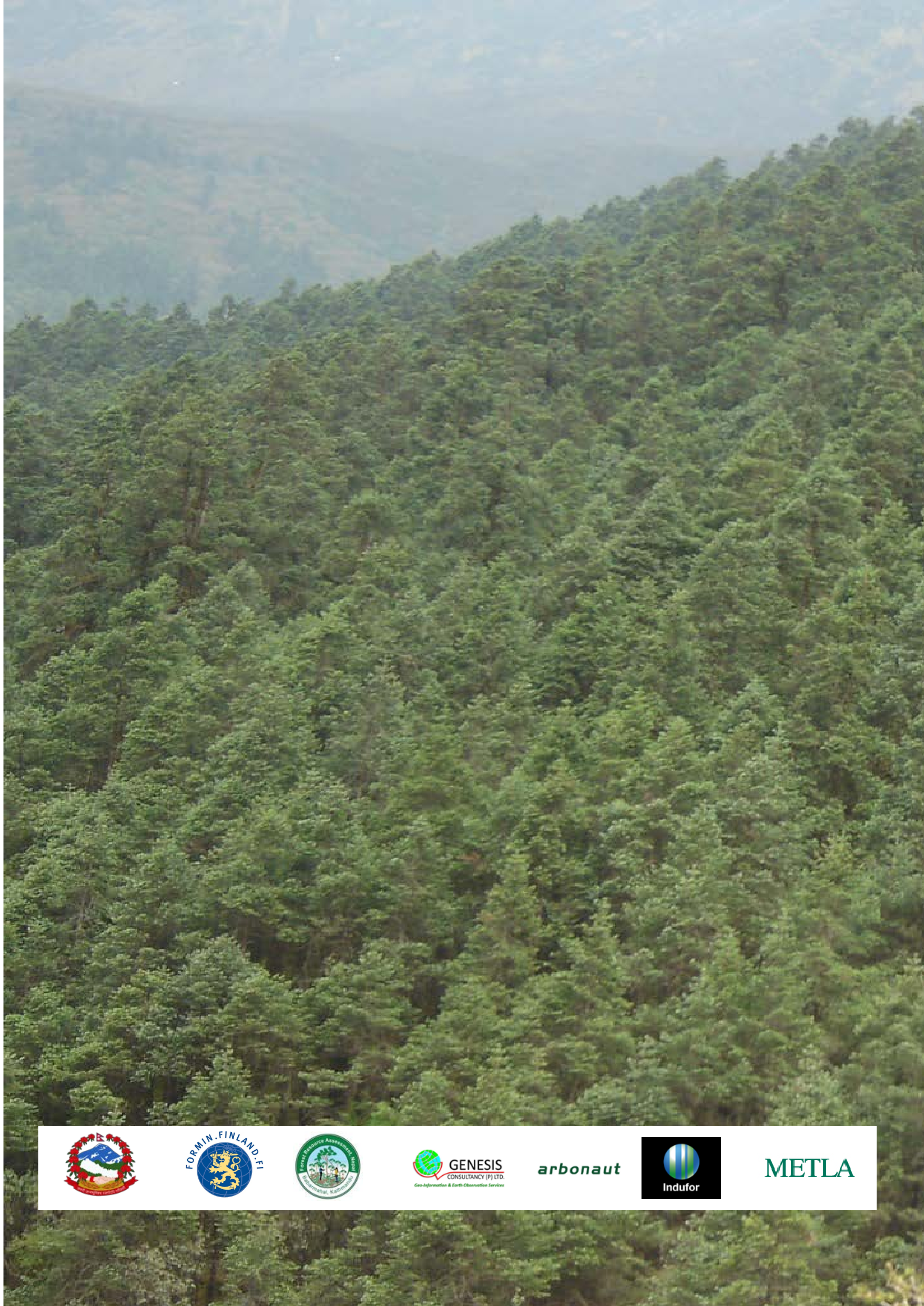
Rhododendron arboreum Smith, Rhododendron arboreum Smith var.album Wall, Rhododendron arboreum Smith var. cinnamomeum, Rhododendron arboreum Smith var. arboretum

Group 15

Aesculus indica (Pangra), *Castanopsis indica* (Dhale Katus), *Neolitsea umbrosa* (Putali), *Persea gamblei* (Kathe Kaulo), *Neolitsea cuipala* (Kalche)

Group 16

Rhododendron barbatum (Chimal), *Rhododendron barbatum var*. barbatum(Chimal), *Rhododendron campanulatum*(Chimal), *Rhododendron campanulatum* var.*campanulatum* (Chimal), *Rhododendron campanulatum* var.wallichii (Chimal), *Rhododendron hodgsonii* (Korling)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