Forest Resource Assessment in Nepal

Manual

on

DATA ANALYSIS AND RESULTS GENERATION

Government of Nepal

Ministry of Forests and Environment

Forest Research and Training Centre

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Abbreviations and Acronyms

ACL	Assistant Crew Leader
BZ	Buffer Zone
CC	Crown Cover
CCSP	Concentric Circular Sample Plot
CFUG	Community Forestry User Group
CL	Crew Leader
DFO	Divisional Forest Officer
DFRS	Department of Forest Research and Survey
E	East
FAO	Food and Agriculture Organization of the United Nations
FRA	Forest Resource Assessment
FRTC	Forest Research and Training Centre
GFRA	Global Forest Resource Assessment
GIS	Geographic Information System
GPS	Global Positioning System
IAS	Invasive Alien Species
LRMP	Land Resource Management Project
LRP	Local Resource Person
N	North
NE	North East
NR	Non-reachable
NTFP	Non-Timber Forest Product
NW	North West
QA	Quality Assurance
QC	Quality Control
RS	Remote Sensing
S	South
SE	South East
SOP	Standard Operating Procedures
SP	Soil Pit
SW	South West
TA	Technical Assistant
TOF	Trees Outside Forest
UN-REDD	United Nations' program "Reducing Emissions from Deforestation and Forest Degradation in Developing Countries"
UTM	Universal Transverse Mercator
VDC	Village Development Committee
VP	Vegetation Plot
W	West
WGS	World Geodetic System
WRB	World Reference Base
FCPF	Forest Carbon Partnership Facility

Definition of Variables

Breast height: A fixed height of 1.3 meters above the ground level. If the ground level cannot be defined, the breast height is determined as 1.3 meters from the seeding point.

Sample tree: A tree selected for the measurement of additional variables (e.g. tree height) that are often generalized to cover the tally trees.

Sapling: Sapling is a tall perennial woody plant having a main trunk and branches forming a distinct elevated crown; includes both gymnosperms and angiosperms. Sapling generally has greater than 1.3 m height and having a diameter at breast height less than 5 cm.

Seedling: Seedling is a young plant saprophyte developing out of a plant embryo from a seed. Seedling development starts with germination of the seed having a height less than 1.3 m. It can be considered as regeneration materials.

Shrub: Shrubs are woody perennial plants, generally of more than 0.5 m and (usually) less than 5 m in height on maturity and **without** a definite stem, i.e. they produce several shoots or trunks from the base. It has several stems, none of which is dominant. When much-branched and dense, it may also be called bush. These distinctions cannot be regarded as unambiguous. In fact, under especially favorable environmental conditions, some shrubs (e.g. *Rhododendron* spp.) may grow to the size of tree like having the dimensions and form of a (small) tree.

Stump height: stump height should measure at 15 cm above from the ground level.

Stump: Remaining part of cut tree usually height is less than 1.3 m.

Tally tree: A tree within the plot fulfilling the diameter threshold determined by the plot radius including stump and climber.

Tree: A perennial woody plant that has many secondary branches clearly above the ground on a single main stem or trunk with clear apical dominance.

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1. Background

1.1 Introduction

Periodic monitoring of forests is essential to examine the total extent and changes over time. Forest Research and Training Centre (FRTC) has a mandate to conduct nationwide forest resource assessment (FRA) and monitor the forest resources periodically.

Updates on data and status of natural resources are vital to policy formulation and policy change which have an ultimate role to economic growth of any country. The information obtained supports forest-related decision-making at international, national and sub-national levels by providing timely, relevant and reliable information (Arnold *et al.,* 2014).

Nepal is a member country of several international programs, conventions and protocols. Food and Agriculture Organization of the United Nations (UN-FAO) updates results on global forest resource assessment every five years and requests forestry data to the national correspondents (FRTC for Nepal). Alongside, Nepal is one of the leading REDD+ countries under the World Bank's Forest Carbon Partnership Facility (FCPF) for which a robust and transparent information system linked to a good database of environmental, social and economic aspects of all the activities is necessary.

FRTC has been involved continuously in the forest resource assessments since 1960s. However, systematic resource assessment having permanency of sample plots to monitor forests at a regular interval started since FRA (2010-2014). In this regard, the second periodic FRA has been conducted since year 2016 and the third since 2021. During the FRA (2010-2014), the FRA data were stored in a pgAdmin (an open source database) and analyzed in PostgreSQL with supplementary tasks (on result generations) in MS Excel. However, the existing database system could not be continued after FRA (2010-2014) due to database system failure and lack of technical manpower in FRTC to diagnose and recover the system. A brief overview of FRA (2010-2014) activities regarding data and analysis is presented in the table 1.

Table *1: Overview of components in overall FRA system and identified gaps.*

SN	Task	List of Activities	Methodology used (FRA 2010-2014)	Methodology used (FRA Re-measurement 2016 onwards
1	**FRA data acquisition**			
1.1		FRA design	FRA document	FRA document
1.2		FRA field inventory and data collection	FRA field manual	FRA field manual
1.3		Image data acquisition	Rapid Eye 5m (year 2010)	National Land Cover Monitoring System (NLCMS)
2	**System development**			
2.1		Data entry software	Zava-based system	COLLECT (OpenForis application)
2.2		Database (Data storage)	PostGres	Ms Excel
2.3		Data analysis software	PostGreSQL, R	Rstudio, Ms Excel
2.4		Forest mapping tool	Erdas, ArcMap, Ecognition	Google Earth Engine
2.5		Reporting platform	PostGres and Excel	Rstudio, Ms Excel
3	**Data analysis**			
3.1		Data validation	PostGreSQL, Excel	Rstudio, Ms Excel
3.2		Preliminary analysis (tree per ha, basal area per ha, etc.)	PostGreSQL	Rstudio, Ms Excel
3.3		Diameter-height modeling	R (lmfor package)	R (lmfor package)
3.4		Gross volume calculation	PostGreSQL	Rstudio, Ms Excel
3.5		Volume ratio generation	Rstudio	Rstudio
3.6		Net volume calculation Vol per ha Top ratio (vol up to 10 cm and 20 cm) Bark ratio	PostGreSQL	Rstudio, Ms Excel
3.7		Biomass calculation Mass of stem Mass of foliage Mass of branch	PostGreSQL	Rstudio, Ms Excel
3.8		Stump volume calculation	PostGreSQL	Rstudio, Ms Excel

3.9		Biomass and Carbon calculation	PostGreSQL	Rstudio, Ms Excel
3.10		Soil data analysis Soil pH Soil NPK analysis Soil organic carbon assessment	Ms Excel	Ms Excel
3.11		Forest mapping Forest cover map Forest change (gain & loss maps)	Erdas, ArcMap, Ecognition	Google Earth Engine
3.12		Error calculation	PostGreSQL	Rstudio, Ms Excel
4	**Reporting**			
		Inventory Result generation	PostGreSQL	Rstudio, Ms Excel
		Map generation and web display	Geoserver	NA
		Soil result generation	MS Excel	Rstudio, Ms Excel

1.2 Need for standard operating procedures (SOP)

Smooth operation of national forestry database management and generation of forestry information using a consistent method is essential to maintain standards and follow the general protocols. Standardization of FRA data analysis and result generation is one of the requisites to meeting national and international requirements including MRV under UN-REDD's FCPF, UN-FAO GFRA reporting, etc. Thus, the purpose of this SOP is to improve the provision of adequate forestry data and its processing for national forest policy development and for national level forestry sector decision making in Nepal. National level information is especially required to assess regionally sustainable utilization potentials of forest-based resources. National-level information on forest resources and their development is also needed for committing the country to new international initiatives and processes in relation to climate change mitigation with a focus on deforestation and forest degradation.

Due to the demanding natural conditions of Nepal, it is a justified requirement to efficiently utilize modern data collection, management and processing techniques together with remote sensing -based information to produce cost-efficient inventory procedures. In order to obtain the quality standards for the inventory results, the priority cannot, however, be given to the efficiency requirements instead of firm, statistically sound inventory design. In the ongoing FRA system of Nepal, a special care has been given for the determination of measurement setups appropriate for the long-term monitoring of forest resources and change detection in terms of forest characteristics including soil components. Besides, obtaining growth data for forest modelling and assessing removals and changes in land use are some of the key desirables from later FRAs. Henceforth, scientific and consistent calculations of inventory data is an essential requirement for reliability of generated forestry information.

2. Overview of Data Collection Process

Data are collected in the field following the instructions. In the field, paper field forms are used. The FRA data collection procedures have been standardized following these field manuals updated subsequently:

1. Forest Resource Assessment Nepal, Field Manual 2010.
2. Forest Resource Assessment in Nepal, (Re-Measurement of Permanent Sample Plots), Field Manual (version 1.2), Revised, 2017.
3. Forest Resource Assessment in Nepal (Re-Measurement of Permanent Sample Plots), Field Manual, 2019.
4. Forest Resource Assessment in Nepal (Re-Measurement of Permanent Sample Plots), Field Manual, 2022.

3. Methods of Data Entry and Validation

If possible, immediately after each working day, data are entered in field computers in the camp. Data entry is instructed in a separate document "Data Entry Instructions". The data entry process includes a quality control module.

Several approaches and methods have been used in the previous years for FRA data entry. For instance, a java-based application was developed and used during FRA 2010-2014 for data entry. Later, during re-measurements of permanent sample plots (since 2016), an application named *Collect* under Open Foris has been developed and being used.

Data validation is an essential tool to ensure that the data being used are accurate, clean and helpful at all times. It is a vital part of any application, as it guarantees that results are generated from a clean, valid and useful data. Sometimes, data validation is conducted as an automatic computer checking to ensure that the data entered is sensible and reasonable.

Forest inventory data must be recorded (entered in a database), edited and condensed before they can be processed to generate required information. In addition, data processing procedure must be customized to the specific requirements and design of the inventory itself. It is thus important to consider treatment of data as an integral part of a forest inventory. Data recording and processing should be given careful consideration at the initial planning stage of forest inventory.

For checking the completeness and for avoiding data entry errors, data entry program in Collect has been used in addition to validation in Rstudio and Ms Excel as well. To reduce errors while entering the category type of variables into the database, the data entry application only allows selecting variable values from the predetermined closed lists stored into database.

4. Estimation of Forest Cover (including loss and gain) Area

This section will be available as a different manual of forest mapping under the broader theme of National Land Cover Monitoring System (https://frtc.gov.np/uploads/files/Study%20Report%20Inner-final.pdf). However, the methodology adopted during FRA 2010-2014 is presented hereunder.

Forest cover mapping was done 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. During that period, 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.

4.1 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 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 (Figure 1). Independent check points were collected to assess the level of accuracy.

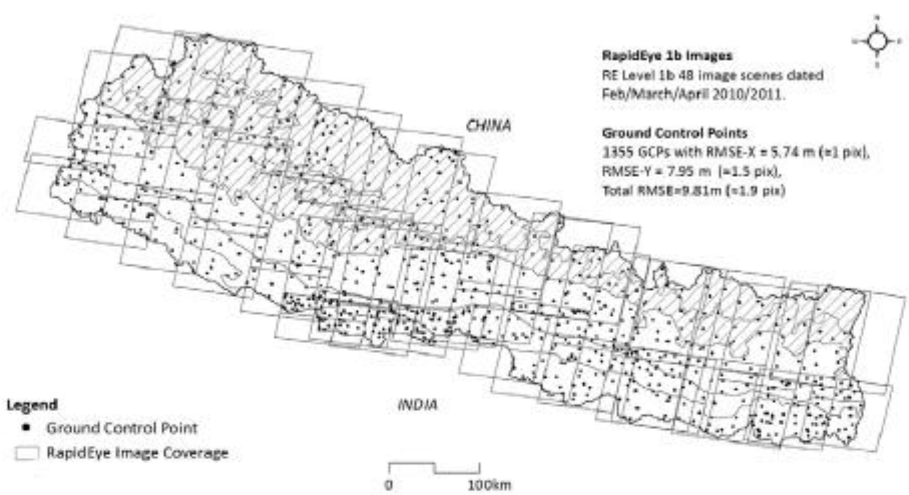

Figure 1: RapidEye image tiles and ground control points used for mapping

Atmospheric Correction of Satellite Images

Atmospheric correction was made to minimize the effects of atmospheric haze and terrain shadows by using topographical normalization and Bidirectional Reflectance Distribution Function (BRDF) correction of the ATCOR3 model (Figure 2), defined by Richter (1998).

Bidirectional reflectance distribution function (BRDF)

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

Where,

G = BRDF factor

B_i = incidence angle

β_T = threshold angle

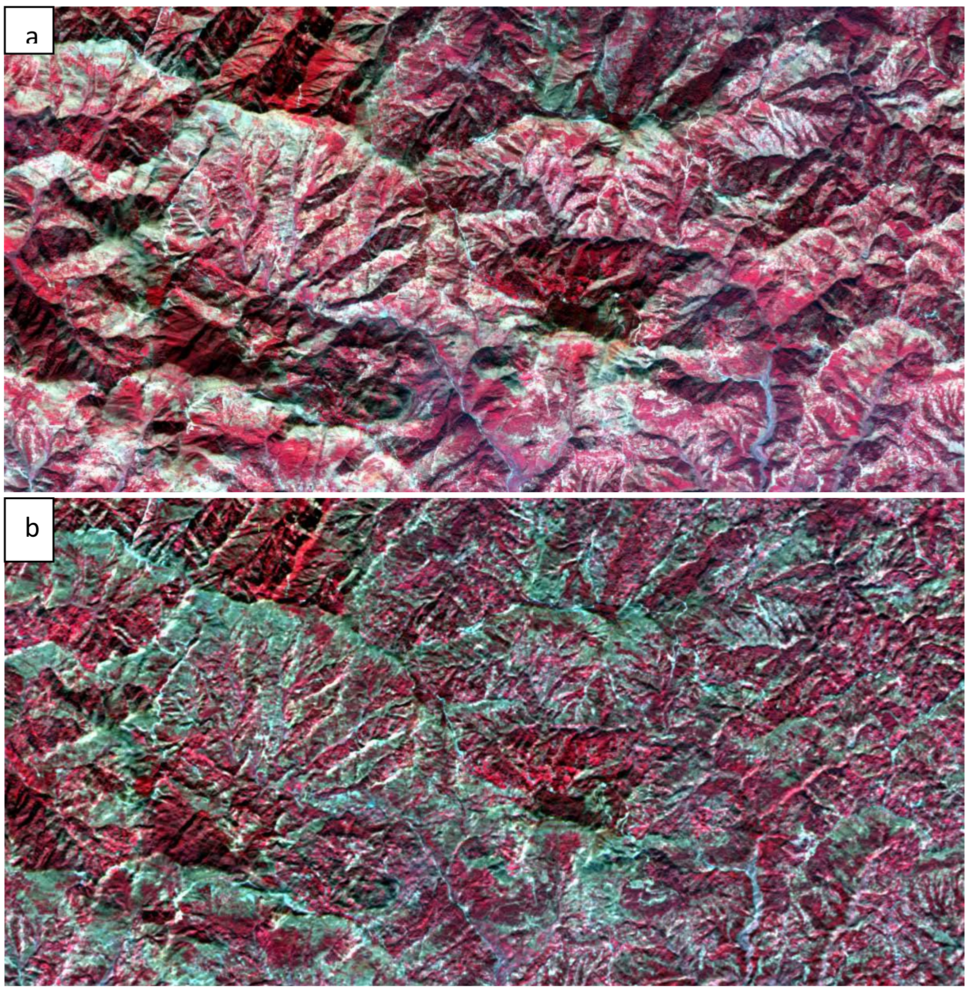

Figure 2: Atmospheric correction; (a) Image before and (b) after atmospheric and BRDF corrections

4.2 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 because of the spatial heterogeneity of the forest patches and complexity of terrain landscape that affected the image classification process.

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 Normalized 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 threefold 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 minimizing 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 in addition to a number of mapping field survey missions. However, due to time and weather limitations in some physiographic regions, the mapping works had to rely mainly 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 maps were assessed by comparing the area classified as forest cover with a number of randomly selected FRA inventory plots.

Forest Patch Mapping

The forest patches and the sizes of those patches were analyzed and mapped over the classified forest cover maps. Spatially contiguous forest patches that fulfilled the criteria for forest were categorized 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 analyzed to assess the distribution and area of forest fragments.

Distribution of Forests by Slope Class

The slopes of forests were spatially analyzed by using a Digital Elevation Model (DEM) 1 created from the national topographic dataset (DoS, 2001). The elevation of each forest pixel (rasterized at a pixel size of 20 m) created from the RapidEye based forest cover were classified into slope groups of <15% (<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 maps. The total forest area under each slope class was also calculated.

5. Calculation of tree level variables

5.1 Trees per hectare

This is used to extrapolate plot level tree numbers to per hectare area. For instance, number of trees and basal area content of an individual tree should be at first extrapolated to the per hectare area. Due to provision of four concentric circles with different radii for trees with different diameters at the breast height, the number of trees per hectare also varies based on the size (DBH) of the tree.

Trees per ha=10000/(4^2*PI())-------------------------------------(i)

For trees with DBH = 5 to 9.9 cm

Trees per ha=10000/(8^2*PI())------------------------------------(ii)

For trees with DBH = 10 to 19.9 cm

Trees per ha=10000/(15^2*PI())------------------------------------(iii)

For trees with DBH =20 to 29.9 cm

Trees per ha=10000/(20^2*PI())------------------------------------(iv)

For trees with DBH > 30 cm

5.2 Correction factor NR

For those sample plots where all area (1256.6 sq. m) were not accessible due to topography and/or terrain (probably some of the trees could not have been measured), the default area cannot be considered effective for extrapolation. In such case, a part of the effective area is needed to be reduced with the help of sketch drawing and stand delineation from the first page of tally sheets.

CF_{NR} = 1 *i.e. a normal situation* (for plots with total area of CCSP not considered as NR in sketch drawing and stand delineation)

CF_{NR} < 1 *i.e. an abnormal situation* (for plots with a certain part of the CCSP considered as NR in sketch drawing and stand delineation)

For any abnormal situation – while determining the *correction factor* – the correction is applicable to all four concentric circles of the CCSP independently. For instance, NR area to be reduced to derive a net effective area for each circle within a CCSP might differ based on the sketch drawing (Field Form 1). This information, however, is not available in the data entry system; thus, manual revision over the tally sheets (only for multiple stands CCSP with at least one stand of NR) and a thorough speculation of the NR area is required.

5.3 Corrected Trees per hectare

Trees per $ha_{corrected}$ = Trees per ha * CF_{NR}

5.4 Diameter_P

Same as diameter for trees and prognosed for stumps, cm.

Diameter at breast height is same, as measured from the field, for all trees with crown classes except 9 (i.e. stumps) for which the DBH is predicted.

DBH_P=DBH measured -----------------------------(i)

For trees with crown classes except 9

DBH= EXP (-0.200345+1.002703 * LN (diameter)) -----------------------------(ii)

For trees with crown class 9

Model (LN(DBH)= a+b ln(D15)) developed by Sharad Baral and Ananda Khadka in 2012 during FRA Terai calculations.

5.5 Basal Area (Tree) sq.m.

It is the basal area of an individual tree in square meter. Literally, the basal area is an area of circular section of the tree at its 1.3 m height (DBH section).

BA = PI()*(DBH_P)^2/40000

5.6 Basal Area (Hectare) sq.m.

It is the tree level extrapolated values for per hectare area.

BA per ha = Trees per $ha_{corrected}$ * BA

5.7 Height_ M

The heights measured and recorded from the field often consist heights of leaning trees for which the real length of trees are to be calculated as follows:

height_m = Sqrt (base^2 + height^2)---------------- (i)

For trees with crown_class<9 and height>0 and base>0 and (base_slope=0 OR base_slope=-9999))

height_m = Sqrt (base^2 + (height-sqrt(base_slope^2-base^2))^2) ---------------- (ii)

For trees with crown_class<9 and height>0 and base>0 and base_slope<0)

height_m = Sqrt (base^2 + (height+sqrt(base_slope^2-base^2))^2) ---------------- (iii)

For trees with crown_class<9 and height>0 and base>0 and base_slope>0)

height_m = height---------------- (iv)

For trees with (crown_class<9 and base<=0) and crown_class=10 (climbers)

5.8 Height_P

Heights for only sample trees are measured in FRA field inventories. Thus, the heights for rest of the trees should be imputed later at the initial phase of calculations.

Height imputation

In statistics a word "imputation" means that a statistically reasoned and logical value is substituted for a missing data point or a missing component of a data point. Processing of data stored into the database is used for the generalisation of tree heights measured for sample trees to cover all tally trees. The details of FRA height generalisation in Lmfor package, R is as mentioned in annex 2.

5.9 Height_Used

It is worth noting that the model derived heights are stored into database of FRA for all tallied trees (including both tally and sample trees). However, field measured heights are used in the case of sample trees when calculating inventory results.

H=Height_m --(i)

For sample tree type=1 or 2 (These are trees for which heights have been measured in the field)

H=Height_P ---(ii)

(For other trees, for which model predicted heights are required)

5.10 Volume

It is the total volume of the tree which is calculated with volume functions.

The volume equation developed by Sharma and Pukkala (1990) is used to estimate the volume of standing trees. The following allometric equation is used to estimate stem volume over bark:

Stem volume

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

where,

ln = Natural logarithm to the base 2.71828.

V = Volume (m3) = $\exp [a + b\times\ln(DBH) + c\times\ln(h)]$

d = DBH in cm

h = Total tree height in m

a, b and c are coefficients depending on species.

Note: Values to be divided by 1000 to convert them to m3 *(model gives in cubic dm)*.

5.11 Volume Ratio

The volume of individual broken trees is estimated using a taper curve equation developed by Heinonen *et al.* (1996).

The details of polynomial taper curve and calculation of volume ratio is given in annex 3.

Volume ratio is 1 for all normal trees and is less than 1 for all top broken trees.

5.12 Ratio_Top

Stem volume without bark (up to top 10 cm and 20 cm) is calculated by using equations developed by Sharma and Pukkala (1990) (annex 3). This is a ratio of top volume of a tree with respect to its total volume. The model gives ln for ratio v_10cm/v.

ratio_top=exp(a + b*ln(DBH)--(i)

Top ratio equation is mentioned in equation 2 of annex 1.

5.13 Ratio_10_20cm

This is a ratio of top volume of a tree at 10-20 cm diameter with respect to its total volume. This model gives ln for ratio v_10_20cm/v_10cm.

ratio_10_20cm= exp(a + b*ln(DBH))--(i)

Ratio_10_20cm equation is mentioned in equation 3 of annex 1.

5.14 Bark Ratio

It is the bark ratio of trees expressed in terms of total volume.

ratio_bark = exp(a + b*ln(diameter_p))-------------------------------(i)

Bark ratio is mentioned in equation 4 of annex 1.

5.15 Bark Ratio (10 cm top)

It is the bark ratio of trees at top 10 cm diameter expressed in terms of volume at 10 cm top diameter.

ratio_bark_10cm= exp(a + b*ln(diameter_p))

Bark ratio (10 cm top) is mentioned in equation 5 of annex 1.

5.16 Bark Ratio (20 cm top)

It is the bark ratio of trees at top 20 cm diameter expressed in terms of volume at 20 cm top diameter.

ratio_bark_20cm= exp(a + b*ln(diameter_p))

Bark ratio (20 cm top) is mentioned in equation 6 of annex 1.

5.17 Top Volume
vol_top=ratio_top*vol

5.18 Volume 10-20 cm
vol_10_20cm = ratio_10_20cm*(vol-ratio_top*vol)

5.19 Volume 10 cm per ha
vol_10cm_ha =(1-ratio_bark_10cm)*trees_ha*(vol-vol_top)-----------(i)

For crown_class <= 5 and diameter_p >= 12.5

-- only stems DBH >= 12.5 will give timber > 10 cm at tip

vol_10cm_ha =(1-ratio_bark_10cm) *trees_ha*LEAST((vol-vol_top) , vol*volume_ratio)-----(ii)

For (crown class=6 or (crown class=7 with sample tree type=3)) and diameter_p >= 12.5 cm

vol_10cm_ha = (1-ratio_bark_10cm)*trees_ha*(vol-vol_top) --------(iii)

For crown_class = 7 AND diameter_p >= 12.5

5.20 Volume 20 cm per ha

vol_20cm_ha = (1-ratio_bark_20cm)*trees_ha*(vol-vol_top-vol_10_20cm)----------------(i)

For crown_class<= 5 and vol_10_20cm>0

vol_20cm_ha = (1-ratio_bark_20cm)*trees_ha*LEAST((vol-vol_top-vol_10_20cm) , vol*volume_ratio)----------------(ii)

For (crown_class = 6 or (sample_tree = 3 and crown_class<=7)) and vol_10_20cm>0

vol_20cm_ha = (1-ratio_bark_20cm)*trees_ha*(vol-vol_top-vol_10_20cm) ---------------(iii)

For crown_class = 7 AND vol_10_20cm>0

5.21 Bark Volume
vol_bark=ratio_bark*volume_ratio*(vol),

5.22 Stem Mass (Biomass)
The biomass models prescribed by MPFS (1989) are used to estimate the biomass of standing trees. The air-dried biomass values obtained by using these equations are then converted into oven-dried biomass values.

Stem biomass = Stem vol. × Density
where,

Vol. = Stem volume in m3
Density = Air-dried wood density in kg/m3

mass_stem = volume_ratio*vol*density (For all trees except climbers and stumps)

Density of tree species is mentioned in annex 4

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

5.23 Branch Mass

mass_branch = bps_repr_pole*mass_stem--------------------------(i)

For crown_class<=6 and (diameter>0 & diameter<10)

mass_branch = (((diameter-10)*bps_small_timber + (40-diameter) *bps_repr_pole)/30) * mass_stem--------------------------(ii)

For crown_class<=6 and (diameter>=10 & diameter<40))

mass_branch = (((diameter-40)*bps_large_timber + (70-diameter)*bps_small_timber) / 30) * mass_stem --------------------------(iii)

For crown_class<=6 and (diameter>=40 & diameter<70)

mass_branch = bps_large_timber*mass_stem------------------------(iv)

For crown_class<=6 and diameter>=70

Branch Ratio (bps) of tree species is mentioned in annex 5

5.24 Foliage Mass

mass_foliage = fps_repr_pole*mass_stem------------------------------------(i)

For crown_class<=6 and (diameter>0 & diameter<10))

mass_foliage = (((diameter-10)*fps_small_timber + (40-diameter)* fps_repr_pole)/30) * mass_stem---------------------------------(ii)

For crown_class<=6 and (diameter>=10 & diameter<40))

mass_foliage = (((diameter-40)*fps_large_timber + (70-diameter)*fps_small_timber) /30) * mass_stem-------------------------------------(iii)

For crown_class<=6 and (diameter>=40 & diameter<70))

mass_foliage = fps_large_timber*mass_stem------------------------------------(iv)

For crown_class<=6 and diameter>=70

Foliage ratio (fps) of tree species is mentioned in annex 5

5.25 Stump Volume

It is the volume of stumps of trees expressed in cubic meter. Stump volume is firstly computed for stumps and also for trees, however, removal from the forest stand is calculated based on existing stumps only.

vol_stump= ((((diameter/(15^0.1229)/0.5248)^(1/1.0063))/100)^2)/4*0.15*pi()*1.5---(i)

For crown_class<=8

-- diameter at 15 dm calculated using same function as when calculated diameter_p (see 5.4 above)

-- stump measurement at 15 cm height, but now function used for d_stump=f(diameter)

vol_stump=(diameter/100)^2/4*0.15*pi()*1.5---(ii)

For crown_class=9 and height=0

-- 15 cm for stump_height used if recorded 0

vol_stump= (diameter/100)^2/4*height*pi()*1.5--------------------------------(iii)

For crown_class=9 and height >0

5.26 Stump Mass

mass_stump = vol_stump*density

For all trees and stumps, but not climbers

Density of tree species is mentioned in annex 4

5.27 Air Dry Total Mass

Air dry mass is sum of mass from different sections of a tree, for instance, stem, branch, foliage and stump.

total_mass_air_dry = mass_stem_ha + mass_branch_ha + mass_foliage_ha + mass_stump_ha

5.28 Oven Dry Total Mass

The air-dried biomass values obtained are then converted into oven-dried biomass values by using a conversion factor of 0.91 (Chaturvedi, 1982; Kharal and Fujiwara, 2012).
Biomass (oven dry) is estimated using the following equation:

total_oven_dry_mass = total_mass_air_dry/1.1

Below-ground biomass:

This estimation is done by using a default value as recommended by IPCC (2006). The value of 0.25 is 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 is not incorporated.

5.29 Carbon

The carbon content was estimated from oven-dried biomass by multiplying the biomass with a carbon-ratio factor of 0.47 (IPCC, 2006).

carbon = total_oven_dry_mass * 0.47

5.30 Reliability of the results

The variance of mean volume estimate in forest can be estimated by using the variance estimator of a ratio estimator as given below (Cochran, 1977).

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

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.

6. Calculation of dead wood and disturbances

Dead woods and disturbances are important parts to understand the forest ecology and forest dynamics. This is why the FRA in Nepal from its early period incorporated the data collection and analysis of dead woods and disturbances.

6.1 Calculation of volume from dead woods

Since, total length and diameters at both ends of the dead woods, logs, branches, etc. have been recorded from the field, Smalian's formula is the best suited to calculate the dead wood volumes.

$Vol = (S_1+S_2) * L$

Where,

$S_1=3.1416*D_1^2/4*1/10000$

(S_1=basal area of log at tip in m^2 and D_1=diameter at tip in cm)

$S_2=3.1416*D_2^2/4*1/10000$

(S_2=basal area of log at base in m^2 and D_2=diameter at base in cm)

L=Length of log in m

6.2 Calculation of disturbances

Disturbances in FRA are recorded in terms of intensity (low, medium and high) of severity caused by particular disturbance. Disturbance can be assessed in terms of plot or cluster since huge variation in natural or anthropogenic disturbances cannot be expected within the small geographical location.

Forest disturbances in FRA Nepal are categorized 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 resigntapping, 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)

Following results can have been drawn regarding forest disturbances:

1. Incidence of observed disturbances in forest plots (overall)
2. Management regimes and their proximity to the forest edge
3. Forest disturbances and their proximity to the forest edge
4. Forest disturbances and their relation to management regime

7. Calculation of shrubs, seedlings and saplings

7.1 Following results can be derived from FRA shrub data

I. Shrub cover percentage overall (average by plots)
II. Shrub cover percentage by cardinal directions (average by plots)
III. Number of shrubs per hectare
IV. Number of shrubs per hectare by species
V. Mean diameter of shrubs by species
VI. Mean height of shrubs by species

7.2 Following results can be derived from FRA seedling and sapling data

I. Number of seedlings and saplings per hectare
II. Number of seedlings and saplings per hectare by species
III. Mean diameter of seedlings and saplings by species

8. Calculation of soil organic carbon and other soil parameters

Organic carbon stock in both the litter and debris fractions are 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 are analyzed in the laboratory, and then the results calculated per hectare are combined with the characteristics of the forest stand and inventory cluster.

The final SOC value is obtained after correcting laboratory values with a consideration of the degree of stoniness determined in the field. This correction is 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 is used. For a correct estimate, the SOC content has to be reduced by the corresponding proportion of stones in soil.

8.1 Assessment of Composite Samples of Litter and Woody Debris

Litter and debris fractions are collected from 1 m^2 circular spots located on the surface of each soil pit before it was dug. Litter and woody debris are 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 is 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 are 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) is very large, small representative sub-samples are set aside so that their dry masses can be determined in the laboratory.

Sampling of Soil

The samples have been 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 is 107.5 cm3.

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

8.2 Analyses in the Laboratory

Determination of Physical Parameters

The composite samples of soil and sub-samples of litter and woody debris are analyzed in the DFRS Soil Laboratory in Babarmahal, Kathmandu. SOC stock is 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) is 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 are found in the volumetrically cored samples is eliminated when calculating the bulk density of the fine fraction.

Determination of Soil Organic Carbon

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

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

The soil samples arrived at the laboratory in field moisture conditions, so air drying is used immediately in order to stabilize them. Then they are oven-dried to achieve a constant mass and moisture content.

Walkley-Black wet combustion method with titration analytics is 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 is applied. An application (e.g. Excel) is used to collect, organize, and speed up laboratory calculations. The application also calculates the carbon stocks of litter, woody debris, and the fine soil fraction.

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

8.3 Compilation of SOC Stock Estimates

The SOC stock, measured in g/m2, in the 30 cm topsoil is calculated by using the following equation:

SOC stock in 30 cm of top soil

SOC(0-30 cm), g/m2 = OCFF * BDFF * 300000 * (1 – Stoniness)

Where,

OCFF denotes the proportion (0–1) of organic carbon (OC) in the soil fine fraction (FF),

BDFF is bulk density of soil fine fraction, g/cm3,

300,000 is the coefficient for volume (cm3) 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 are, as convention prescribes, scaled up to t/ha prior to use for reporting.

8.4 Estimation of Mean and Standard Errors

The carbon contents of soil, litter and debris are 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 (2010-2014), the Institutional Cooperation Instrument Nepal-Project compared the SOC results from Terai soil plots determined by the then DFRS Soil Laboratory and Metla Soil Laboratory in Finland (DFRS/FRA, 2014). 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.

FRTC laboratory uses the Walkley-Black wet combustion method.

9. Biodiversity assessment (including NTFPs, ToF, epiphytes, parasites, climbers, mammals and other herbaceous diversity

The lists of flora and fauna species obtained from the field sample plots (qualitative methods) should be first verified by using various other sources (Edwards 1996; DPR, 2007; Flora of Nepal (www.eflora.org), and Bhuju et al., 2007) and earlier FRA reports. Annotated lists can be prepared by incorporating the plot level data.

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

Frequencies of tree species (the proportion of sampling units containing a given tree species) can be 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

The Shannon-Weaner diversity index can be used to calculate species diversity as shown in Equation 8.

Equation 8: *Shannon-Weaner diversity index*

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

Where,

= 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

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Annex 1: Equations for Volume and Bark Ratio

id	equation	number	genus	species	Local name	definition	a	b	c	sf	Remarks
1	1	1	Abies	Abies pindrow	Gobre salla	NA	-2.4453	1.722	1.0757	0.1	Total Volume
2	1	2	Acacia	Acacia catechu	Khair	NA	-2.3256	1.6476	1.0552	0.12	Total Volume
3	1	3	Adina	Adina cordifolia	Haldu	NA	-2.5626	1.8598	0.8783	0.14	Total Volume
5	1	5	Alnus	Alnus nepalensis	Utis	NA	-2.7761	1.9006	0.9428	0.13	Total Volume
6	1	6	Anogeissus	Anogeissus latifolia	Banjhi	NA	-2.272	1.7499	0.9174	0.11	Total Volume
7	1	7	Bombax	Bombax malabaricum	NA	NA	-2.3865	1.7414	1.0063	0.11	Total Volume
8	1	8	Cedrela	Cedrela toona	Toon	NA	-2.1832	1.8679	0.7569	0.14	Total Volume
9	1	9	Dalbergia	Dalbergia sissoo	Sissoo	NA	-2.1959	1.6567	0.9899	0.12	Total Volume
10	1	10	Eugenia	Eugenia jambolana	Jamun	NA	-2.5693	1.8816	0.8498	0.12	Total Volume
11	1	11	Hymanodictyon	Hymanodictyon excelsum	Bhurkul	NA	-2.585	1.9437	0.7902	0.11	Total Volume

12	1	12	Lagerstroemia	Lagerstroemia parviflora	Botdhairo	NA	-2.3411	1.7246	0.9702	0.14	Total Volume
13	1	13	Michelia	Michelia champaca	Champ	NA	-2.0152	1.8555	0.763	0.14	Total Volume
14	1	14	Pinus	Pinus roxburghii	Chir Pine	NA	-2.977	1.9235	1.0019	0.1	Total Volume
15	1	15	Pinus	Pinus wallichiana	Blue Pine	NA	-2.8195	1.725	1.1623	0.12	Total Volume
16	1	16	Quercus	spp	NA	NA	-2.36	1.968	0.7469	0.14	Total Volume
17	1	17	Schima	Schima wallichii	Chilaune	NA	-2.7385	1.8155	1.0072	0.12	Total Volume
18	1	18	Shorea	Shorea robusta	Sal	NA	-2.4554	1.9026	0.8352	0.13	Total Volume
19	1	19	Terminalia	Terminalia tomentosa	Asna	NA	-2.4616	1.8497	0.88	0.12	Total Volume
20	1	20	Trewia	Trewia nudiflora	Gutel	NA	-2.4585	1.8043	0.922	0.12	Total Volume
21	1	21	Tsuga	spp.	NA	Hemlock	-2.5293	1.7815	1.0369	0.08	Total Volume
22	1	22	ClassA	NA	NA	Miscellaneous in Terai	-2.3993	1.7836	0.9546	0.16	Total Volume
23	1	23	ClassB	NA	NA	Miscellaneous in Hills	-2.3204	1.8507	0.8223	0.14	Total Volume

24	2	1	Abies	Abies pindrow	Gobre salla	NA	5.4443	-2.6902	-999	0.49	Top Ratio
25	2	2	Acacia	Acacia catechu	Khair	NA	5.4401	-2.491	-999	0.39	Top Ratio
26	2	3	Adina	Adina cordifolia	Haldu	NA	5.4681	-2.4398	-999	0.57	Top Ratio
27	2	4	Albizzia	spp	Sisris	NA	4.4031	-2.2094	-999	0.46	Top Ratio
28	2	5	Alnus	Alnus nepalensis	Utis	NA	6.019	-2.7271	-999	0.51	Top Ratio
29	2	6	Anogeissus	Anogeissus latifolia	Banjhi	NA	4.9502	-2.3353	-999	0.41	Top Ratio
30	2	7	Bombax	Bombax malabaricum	NA	NA	4.5554	-2.3009	-999	0.54	Top Ratio
31	2	8	Cedrela	Cedrela toona	Toon	NA	4.9705	-2.3436	-999	0.45	Top Ratio
32	2	9	Dalbergia	Dalbergia sissoo	Sissoo	NA	4.358	-2.1559	-999	0.45	Top Ratio
33	2	10	Eugenia	Eugenia jambolana	Jamun	NA	5.1749	-2.3636	-999	0.44	Top Ratio
34	2	11	Hymanodictyon	Hymanodictyon excelsum	Bhurkul	NA	5.5572	-2.496	-999	0.52	Top Ratio
35	2	12	Lagerstroemia	Lagerstroemia parviflora	Botdhairo	NA	5.3349	-2.4428	-999	0.51	Top Ratio

36	2	13	Michelia	Michelia champaca	Champ	NA	3.3499	-2.0161	-999	0.51	Top Ratio
37	2	14	Pinus	Pinus roxburghii	Chir Pine	NA	6.2696	-2.8252	-999	0.47	Top Ratio
38	2	15	Pinus	Pinus wallichiana	Blue Pine	NA	5.7216	-2.6788	-999	0.5	Top Ratio
39	2	16	Quercus	spp	NA	NA	4.8511	-2.4494	-999	0.65	Top Ratio
41	2	18	Shorea	Shorea robusta	Sal	NA	5.2026	-2.4788	-999	0.51	Top Ratio
42	2	19	Terminalia	Terminalia tomentosa	Asna	NA	4.5968	-2.2305	-999	0.55	Top Ratio
43	2	20	Trewia	Trewia nudiflora	Gutel	NA	5.3475	-2.4774	-999	0.54	Top Ratio
44	2	21	Tsuga	spp.	NA	Hemlock	5.2774	-2.6483	-999	0.41	Top Ratio
45	2	22	ClassA	Miscellaneous in Terai			4.8991	-2.3406	-999	0.63	Top Ratio
46	2	23	ClassB	Miscellaneous in Hills			5.5323	-2.4815	-999	0.5	Top Ratio
47	3	1	Abies	Abies pindrow	Gobre salla	NA	9.0316	-3.1527	-999	0.51	Ratio 10-20 cm

48	3	2	Acacia	Acacia catechu	Khair	NA	8.3845	-2.8693	-999	0.43	Ratio 10-20 cm
49	3	3	Adina	Adina cordifolia	Haldu	NA	7.6404	-2.6695	-999	0.52	Ratio 10-20 cm
50	3	4	Albizzia	spp	Sisris	NA	7.9419	-2.7343	-999	0.45	Ratio 10-20 cm
51	3	5	Alnus	Alnus nepalensis	Utis	NA	7.8979	-2.7867	-999	0.48	Ratio 10-20 cm
52	3	6	Anogeissus	Anogeissus latifolia	Banjhi	NA	7.7573	-2.6716	-999	0.44	Ratio 10-20 cm
53	3	7	Bombax	Bombax malabaricum	NA	NA	6.4019	-2.3873	-999	0.52	Ratio 10-20 cm
54	3	8	Cedrela	Cedrela toona	Toon	NA	7.3734	-2.5998	-999	0.49	Ratio 10-20 cm
55	3	9	Dalbergia	Dalbergia sissoo	Sissoo	NA	6.8821	-2.44	-999	0.5	Ratio 10-20 cm
56	3	10	Eugenia	Eugenia jambolana	Jamun	NA	7.6807	-2.6648	-999	0.51	Ratio 10-20 cm
57	3	11	Hymanodictyon	Hymanodictyon excelsum	Bhurkul	NA	6.825	-2.4603	-999	0.48	Ratio 10-20 cm
58	3	12	Lagerstroemia	Lagerstroemia parviflora	Botdhairo	NA	7.2637	-2.5282	-999	0.43	Ratio 10-20 cm

59	3	13	Michelia	Michelia champaca	Champ	NA	6.7852	-2.4567	-999	0.46	Ratio 10-20 cm
60	3	14	Pinus	Pinus roxburghii	Chir Pine	NA	8.5662	-3.0486	-999	0.53	Ratio 10-20 cm
61	3	15	Pinus	Pinus wallichiana	Blue Pine	NA	8.1696	-2.8862	-999	0.48	Ratio 10-20 cm
62	3	16	Quercus	spp	NA	NA	7.0779	-2.5739	-999	0.55	Ratio 10-20 cm
63	3	17	Schima	Schima wallichii	Chilaune	NA	8.5074	-2.8908	-999	0.51	Ratio 10-20 cm
64	3	18	Shorea	Shorea robusta	Sal	NA	8.156	-2.8365	-999	0.51	Ratio 10-20 cm
65	3	19	Terminalia	Terminalia tomentosa	Asna	NA	7.4095	-2.6093	-999	0.48	Ratio 10-20 cm
66	3	20	Trewia	Trewia nudiflora	Gutel	NA	7.448	-2.6313	-999	0.39	Ratio 10-20 cm
67	3	21	Tsuga	spp.	NA	Hemlock	7.5935	-2.7629	-999	0.47	Ratio 10-20 cm
68	3	22	ClassA	NA	NA	Miscellaneous in Terai	6.7548	-2.4589	-999	0.45	Ratio 10-20 cm
69	3	23	ClassB	NA	NA	Miscellaneous in Hills	7.0759	-2.5336	-999	0.5	Ratio 10-20 cm

70	4	1	Abies	Abies pindrow	NA	NA	-0.0552	-0.4804	-999	0.24	Bark Ratio
71	4	2	Acacia	Acacia catechu	Khair	NA	0.0368	-0.4852	-999	0.17	Bark Ratio
72	4	3	Adina	Adina cordifolia	Haldu	NA	-0.4428	-0.2575	-999	0.13	Bark Ratio
73	4	4	Albizzia	spp	Sisris	NA	0.3809	-0.5361	-999	0.21	Bark Ratio
74	4	5	Alnus	Alnus nepalensis	Utis	NA	-1.3593	-0.2015	-999	0.18	Bark Ratio
75	4	6	Anogeissus	Anogeissus latifolia	Banjhi	NA	-0.2512	-0.6053	-999	0.14	Bark Ratio
76	4	7	Bombax	Bombax malabaricum	NA	NA	1.0876	-0.6846	-999	0.15	Bark Ratio
77	4	8	Cedrela	Cedrela toona	Toon	NA	0.33	-0.4853	-999	0.15	Bark Ratio
78	4	9	Dalbergia	Dalbergia sissoo	Sissoo	NA	-0.0408	-0.4218	-999	0.24	Bark Ratio
79	4	10	Eugenia	Eugenia jambolana	Jamun	NA	-0.1451	-0.3617	-999	0.21	Bark Ratio
80	4	11	Hymanodictyon	Hymanodictyon excelsum	Bhurkul	NA	0.4405	-0.4755	-999	0.15	Bark Ratio

81	4	12	Lagerstroemia	Lagerstroemia parviflora	Botdhairo	NA	0.6336	-0.6531	-999	0.19	Bark Ratio
82	4	13	Michelia	Michelia champaca	Champ	NA	-0.1672	-0.4535	-999	0.2	Bark Ratio
83	4	14	Pinus	Pinus roxburghii	Chir Pine	NA	1.1876	-0.7029	-999	0.24	Bark Ratio
84	4	15	Pinus	Pinus wallichiana	Blue Pine	NA	0.2438	-0.6214	-999	0.2	Bark Ratio
85	4	16	Quercus	spp	NA	NA	-0.4146	-0.4193	-999	0.26	Bark Ratio
86	4	17	Schima	Schima wallichii	Chilaune	NA	0.9782	-0.5657	-999	0.22	Bark Ratio
87	4	18	Shorea	Shorea robusta	Sal	NA	0.1372	-0.4182	-999	0.14	Bark Ratio
88	4	19	Terminalia	Terminalia tomentosa	Asna	NA	0.0572	-0.4114	-999	0.17	Bark Ratio
89	4	20	Trewia	Trewia nudiflora	Gutel	NA	-0.4918	-0.4689	-999	0.15	Bark Ratio
90	4	21	Tsuga	spp.	NA	Hemlock	-0.2186	-0.4796	-999	0.16	Bark Ratio
91	4	22	ClassA	NA	NA	Miscellaneous in Terai	0.1634	-0.5581	-999	0.35	Bark Ratio

92	4	23	ClassB	NA	NA	Miscellaneous in Hills	-0.3878	-0.3159	-999	0.25	Bark Ratio
93	5	1	Abies	Abies pindrow	Gobre salla	NA	-0.0615	-0.4786	-999	0.24	Bark Ratio Top (10cm)
94	5	2	Acacia	Acacia catechu	Khair	NA	0.2306	-0.553	-999	0.16	Bark Ratio Top (10cm)
95	5	3	Adina	Adina cordifolia	Haldu	NA	-0.1764	-0.3302	-999	0.17	Bark Ratio Top (10cm)
96	5	4	Albizzia	spp	Sisris	NA	0.7955	-0.6634	-999	0.18	Bark Ratio Top (10cm)
97	5	5	Alnus	Alnus nepalensis	Utis	NA	-1.4088	-0.2123	-999	0.18	Bark Ratio Top (10cm)
98	5	6	Anogeissus	Anogeissus latifolia	Banjhi	NA	-0.3033	-0.5919	-999	0.14	Bark Ratio Top (10cm)
99	5	7	Bombax	Bombax malabaricum	NA	NA	1.1938	-0.7262	-999	0.16	Bark Ratio Top (10cm)
100	5	8	Cedrela	Cedrela toona	Toon	NA	0.3475	-0.4968	-999	0.16	Bark Ratio Top (10cm)
101	5	9	Dalbergia	Dalbergia sissoo	Sissoo	NA	-0.1498	-0.3802	-999	0.22	Bark Ratio Top (10cm)
102	5	10	Eugenia	Eugenia jambolana	Jamun	NA	0.2571	-0.4715	-999	0.21	Bark Ratio Top (10cm)
103	5	11	Hymanodictyon	Hymanodictyon excelsum	Bhurkul	NA	0.4562	-0.489	-999	0.15	Bark Ratio Top (10cm)

104	5	12	Lagerstroemia	Lagerstroemia parviflora	Botdhairo	NA	0.7698	-0.7061	-999	0.24	Bark Ratio Top (10cm)
105	5	13	Michelia	Michelia champaca	Champ	NA	0.0244	-0.5005	-999	0.2	Bark Ratio Top (10cm)
106	5	14	Pinus	Pinus roxburghii	Chir Pine	NA	1.1763	-0.6997	-999	0.24	Bark Ratio Top (10cm)
107	5	15	Pinus	Pinus wallichiana	Blue Pine	NA	0.4925	-0.6517	-999	0.28	Bark Ratio Top (10cm)
108	5	16	Quercus	spp	NA	NA	-0.4224	-0.4184	-999	0.26	Bark Ratio Top (10cm)
109	5	17	Schima	Schima wallichii	Chilaune	NA	0.8683	-0.5659	-999	0.22	Bark Ratio Top (10cm)
110	5	18	Shorea	Shorea robusta	Sal	NA	0.1448	-0.4202	-999	0.14	Bark Ratio Top (10cm)
111	5	19	Terminalia	Terminalia tomentosa	Asna	NA	0.0672	-0.4154	-999	0.17	Bark Ratio Top (10cm)
112	5	20	Trewia	Trewia nudiflora	Gutel	NA	-0.857	-0.3503	-999	0.15	Bark Ratio Top (10cm)
113	5	21	Tsuga	spp.	NA	Hemlock	-0.2181	-0.4797	-999	0.16	Bark Ratio Top (10cm)
114	5	22	ClassA	NA	NA	Miscellaneous in Terai	0.1772	-0.5617	-999	0.35	Bark Ratio Top (10cm)

115	5	23	ClassB	NA	NA	Miscellaneous in Hills	-0.3796	-0.3188	-999	0.25	Bark Ratio Top (10cm)
116	6	1	Abies	Abies pindrow	Gobre salla	NA	-0.8747	-0.2661	-999	0.25	Bark Ratio Top (20cm)
117	6	2	Acacia	Acacia catechu	Khair	NA	-0.0687	-0.4719	-999	0.16	Bark Ratio Top (20cm)
118	6	3	Adina	Adina cordifolia	Haldu	NA	-0.1772	-0.3322	-999	0.15	Bark Ratio Top (20cm)
119	6	4	Albizzia	spp	Sisris	NA	0.7744	-0.6586	-999	0.19	Bark Ratio Top (20cm)
120	6	5	Alnus	Alnus nepalensis	Utis	NA	-1.4061	-0.2124	-999	0.19	Bark Ratio Top (20cm)
121	6	6	Anogeissus	Anogeissus latifolia	Banjhi	NA	-0.5284	-0.535	-999	0.14	Bark Ratio Top (20cm)
122	6	7	Bombax	Bombax malabaricum	NA	NA	1.1557	-0.7155	-999	0.16	Bark Ratio Top (20cm)
123	6	8	Cedrela	Cedrela toona	Toon	NA	0.5925	-0.5622	-999	0.15	Bark Ratio Top (20cm)
124	6	9	Dalbergia	Dalbergia sissoo	Sissoo	NA	0.4042	-0.5267	-999	0.21	Bark Ratio Top (20cm)
125	6	10	Eugenia	Eugenia jambolana	Jamun	NA	0.2314	-0.4654	-999	0.21	Bark Ratio Top (20cm)

126	6	11	Hymanodictyon	Hymanodictyon excelsum	Bhurkul	NA	0.3869	-0.4728	-999	0.14	Bark Ratio Top (20cm)
127	6	12	Lagerstroemia	Lagerstroemia parviflora	Botdhairo	NA	0.5828	-0.6588	-999	0.27	Bark Ratio Top (20cm)
128	6	13	Michelia	Michelia champaca	Champ	NA	0.2137	-0.5466	-999	0.2	Bark Ratio Top (20cm)
129	6	14	Pinus	Pinus roxburghii	Chir Pine	NA	1.2535	-0.7194	-999	0.25	Bark Ratio Top (20cm)
130	6	15	Pinus	Pinus wallichiana	Blue Pine	NA	1.6781	-0.9544	-999	0.26	Bark Ratio Top (20cm)
131	6	16	Quercus	spp	NA	NA	0.3842	-0.6149	-999	0.26	Bark Ratio Top (20cm)
132	6	17	Schima	Schima wallichii	Chilaune	NA	1.0878	-0.6197	-999	0.23	Bark Ratio Top (20cm)
133	6	18	Shorea	Shorea robusta	Sal	NA	0.1672	-0.4271	-999	0.15	Bark Ratio Top (20cm)
134	6	19	Terminalia	Terminalia tomentosa	Asna	NA	0.1515	-0.4299	-999	0.23	Bark Ratio Top (20cm)
135	6	20	Trewia	Trewia nudiflora	Gutel	NA	-0.6019	-0.4163	-999	0.16	Bark Ratio Top (20cm)
136	6	21	Tsuga	spp.	NA	Hemlock	-0.3266	-0.4464	-999	0.24	Bark Ratio Top (20cm)

137	6	22	ClassA	NA	NA	Miscellaneous in Terai	0.551	-0.6544	-999	0.35	Bark Ratio Top (20cm)
138	6	23	ClassB	NA	NA	Miscellaneous in Hills	0.4031	-0.5321	-999	0.22	Bark Ratio Top (20cm)
4	1	4	Albizzia	Albizzia species	Sisris	NA	-2.4284	1.7609	0.9662	0.12	Total Volume
40	2	17	Schima	Schima wallichii	Chilaune	NA	7.4617	-3.0676	-999	0.44	Top Ratio

Annex 2: Diameter height modeling using Lmfor package in R.

1) An input data should be extracted from the database using SQL script tailored for the construction of tally tree list including sample tree characteristics and stand variables required for the estimation of parameters of the nonlinear height generalisation model. The variables in the input data are as follows:

1	id	10	quality_class
2	plot_id	11	crown_class
3	col	12	sample_tree
4	row	13	timest
5	cluster_number	14	selected_for_field
6	plot_number	15	diameter_p
7	tree_number	16	height_m
8	forest_stand	17	forest_type
9	species		

2) The R module reads the tree list, creates a data frame using the original variable names, estimates the parameters for fixed and random model components, and estimates the heights of sample trees and predicts the heights of tally trees.
3) A new data vector entitled "height_p" is created and stored into the initial data frame created using SQL-derived input data.
4) The following script had been used during FRA 2010-2014 to generate diameter-height equations and predict the heights for the trees in R studio.

packake used: lmfor by Lauri Mehtatalo
Example: Height model for the species 6615 (SPP_VOL= S
H_6615<- subset (H,H$H_model=="Sal")

This should be changed for each species and run independently using the species code

modelName<-'wykoff'   # giving modelName as parameter to plot so don't have to change

ImpFixed_6615<-
ImputeHeights(H_6615d,H_6615h,
#H_6615$plot_id,
modelName,level=1,makeplot=TRUE)
summary (ImpFixed_6615$model)

Other models can be tested for better results (e.g. least s.e.)

5) A data frame should be created for calculated heights. This data frame "T" finally should have all trees with modelled heights. And modelled with height model that is specially made for that species. So we will create following datasets:
   a. **T_xxxx:** data frame having selected variables of all trees that have been in the subset
   T_xxxx<-cbind.data.frame((H_xxxxid,H_xxxxcol,H_xxxxrow,H_xxxxplot_number, H_xxxx$tree_number,H_NF$species,H_xxxxd,H_xxxxh,ImpRandom_xxxx$hpred)
   ## names(T_NF)=c("id", "col", "row", "plot_number", "tree_number", "species", "H_model", "d", "h", " hpred")

For example: T_6615<-
cbind.data.frame(H_6615$plot_col,H_6615$plot_row,H_6615$plot_number,
H_6615$tree_no,H_6615$species_code, H_6615H_model, H_6615d,
H_6615$h,ImpFixed_6615$hpred)

names(T_6615)=c("plot_col", "plot_row", "plot_number","tree_no","species_code",
"H_model", "d", "h", "hpred")

!! T_NF<- NULL ## to remove dataset if something goes wrong!!!
H_NF ## name of dataset eg. H_nnnn : so create commands for all modelled individual models and groups
explanation for which species is this modelled height for
#T_NF<-cbind.data.frame(H_NFid,H_NFcol,H_NFrow,H_NFplot_number,
H_NF$tree_number, H_NF$species,H_NFd,H_NFh,ImpRandom_NF$hpred)
#names(T_NF)=c("id", "col", "row", "plot_number", "tree_number","species", "H_model",
"d", "h", "hpred")

b. **S_nnnn**: data frame that will have only those trees the model is for
c. **SS_all**: binding all Height_p in a single table
SS_all <-rbind (T_spp1, T_spp2, T_spp3, ……….., T_spp$_n$)
For example, SS_all<-rbind(T_6651, T_6089, T_6063, T_misc, T_6615, T_sirish, T_6239,
T_6349, T_6090, T_6250, T_6370, T_Barro)

6) An updated tree list is produced for the imputation of missing heights of tally trees in the database The variables of the tree list are as follows:
    1 col
    2 row
    3 cluster_number
    4 plot_number
    5 tree_number
    6 height_p

7) Exporting the csv file with modelled heights:
write.csv(SS_all, "H_p_all_terai_2016.csv")

Annex 3: Volume ratio calculation in R

A volume ratio estimate for the trees with a broken top (value of the crown class variable equals to 6) is obtained as a part of the R-script based processing of height data. The volume ratio variable “volume_ratio” is obtained using information on the field measured height, height obtained using the mixed-effects height generalisation model and a polynomial taper curve model.

An updated tree list is produced for the imputation of missing heights of tally trees in the database The variables of the tree list are as follows:

- col
- row
- cluster_number
- plot_number
- tree_number
- height_p
- volume_ratio

A polynomial taper curve by *Heinonen et al.* was used during FRA 2010-2014 calculations. The function has been used here to determine volumes of broken trees:

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

where: v = predicted stem volume (dmÂ³)

vf = volume (dmÂ³) predicted using models of *Sharma and Pukkala (1990)* and total height predicted using height generalization model for FRA

vcut,int = stem volume (dmÂ³) from stump height (15 cm) to the cut point of tree integrated taper curve model and using height generalization model for FRA

vtot,int = stem volume (dmÂ³) from stump height (15 cm) to the tip of tree integrated taper curve model and using height generalization model for FRA

a1-a3 = parameters of correction polynomial

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

1. Fibonacci function

```
a.par=c(0,0,0)
b.par=c(2.05502,-0.89331,-1.50615,3.47354,-3.10063,1.50246,-0.05514,0.00070)
ht=20; x.m=1-1.3/ht
Fibonacci <- function(x.m, a.par, b.par)
{value=-999
 Pb=(a.par[1]+b.par[1])*x.m   +
  (a.par[2]+b.par[2])*x.m^2  +
```

```
  (a.par[3]+b.par[3])*x.m^3  +
  b.par[4] *x.m^5  +
  b.par[5] *x.m^8  +
  b.par[6] *x.m^13 +
  b.par[7] *x.m^21 +
  b.par[8] *x.m^34
  value=Pb
 value}
```

2. Volume calculation with taper curve

```
v.taper <- function(d13, ht, ht.x, a.par, b.par)

{
 value = -999
 if(ht.x == ht){
  hl    = seq(.15, ht, by=0.01); hl=hl[2:length(hl)]-(0.01/2)
  dl    = d.m.taper(d13, 1-(hl/ht), ht, a.par, b.par)
  value = sum((pi*dl^2/4)/1000)
 }
 if(ht.x  < ht){
  hl.x  = seq(.15, ht.x, by=0.01); hl.x=hl.x[2:length(hl.x)]-(0.01/2)
  dl.x  = d.m.taper(d13, 1-(hl.x/ht), ht, a.par, b.par)
  value = sum((pi*dl.x^2/4)/1000)
 }
 value
}
```

3. Function for calculating volume ratio -------------------------------------

```
v.ratio.broken.top.trees <- function(d13, ht, ht.x, crown_class, a.par, b.par)

{value = 1

 {  v.t.height_p      = v.taper(d13, ht, ht, a.par, b.par)   # volume up to prognosed height (ht),

  v.t.actual.height = v.taper(d13, ht, ht.x, a.par, b.par) # volume to broken top height (to height ht.x)

  value            = v.t.actual.height/v.t.height_p

  # if(value < 0){value = 1}      # height < height_p

 }

 value

}
```

```
# volume_ratio needs to be calculated for trees: crown_class==6 and crown_class (7,8) and sample_tree
==3
# dataset H same as when modeling heights, can be loaded from database with
'read_tree_data_from_potgres_db.R'
# H dataset should be formulated as in above script
# H_broken is subset of trees that need volume_ratio different from default 1.
H_broken <- subset (H,H$crown_class==6 |
          (H$crown_class==7 & H$sample_tree==3 | H$crown_class==8 & H$sample_tree==3)
          )
```

5. **calculating ratio for above trees**

```
# H_broken$volume_ratio = NA    # first all will get N/A
for(i in 1:nrow(H_broken)){
 # case 1 when measured height below modeled ...
 if(( H_broken$height_16[i]  < H_broken$height_pred[i])& H_broken$height_16[i]>0 ){
  H_broken$volume_ratio[i] = v.ratio.broken.top.trees(H_broken$d[i],
                     H_broken$height_pred[i], H_broken$height_16[i],
                     H_broken$crown_class[i], a.par, b.par)}

 # case 2 where measured height is above prognosed height ...
 ##  add 10 % to measured height to get approx. of height without broken
 if( H_broken$height_16[i]  >= H_broken$height_pred[i]){
  H_broken$volume_ratio[i] = v.ratio.broken.top.trees(H_broken$d[i],
                          H_broken$height_16[i]*1.1,
                          H_broken$height_16[i], H_broken$crown_class[i],
                          a.par, b.par)}




 # case 3 when broken tree has no measured height
 if( H_broken$height_16[i] == 0 ){
  H_broken$volume_ratio[i] = v.ratio.broken.top.trees(H_broken$d[i],
                              H_broken$height_pred[i],
                              H_broken$height_pred[i]*0.9,
                              H_broken$crown_class[i], a.par, b.par)}
}
 # Data Export
write.csv(H_broken, "vol_ratio_data.csv")
#write.csv(H_broken$volume_ratio, file =  "Data_broken_trees$volume_ratio.csv",row.names=TRUE)
```

Annex 4: Density of species

ID	Number	Genus	Species	Local Name	Density
1	1	Abies	Abies pindrow	Gobre salla	480
2	2	Abies	Abies spectabilis	Bunga salla	480
3	3	Abies	spp	NA	480
4	4	Acacia	Acacia catechu	Khair	960
5	5	Acer	spp	NA	640
6	6	Adina	Adina cordifolia	Haldu	670
7	7	Albizzia	spp	Sisris	673
8	8	Alnus	Alnus nepalensis	Utis	390
9	9	Anogeissus	Anogeissus latifolia	Banjhi	880
10	10	Betula	Betula utilis	Bhojpatra	700
11	11	Bombax	Bombax malabaricum	NA	368
12	12	Castanopsis	spp	NA	740
13	13	Cedrela	Cedrela toona	Toon	480
14	14	Cedrus	Cedrus deodora	Dyar salla	560
15	15	Cupressus	Cupressus torulosa	Raisalla	600
16	16	Dalbergia	Dalbergia sissoo	Sissoo	780
17	17	Daphniphyllum	Daphniphyllum himalense	Rakta Chandan	640
18	18	Diospyros	Diospyros spp.	NA	840
19	19	Eugenia	Eugenia jambolana	Jamun	770
20	20	Hymanodictyon	Hymanodictyon excelsum	Bhurkul	750
21	21	Juniperus	Juniperus indica	Dhupi	500
22	22	Lagerstroemia	Lagerstroemia parviflora	Botdhairo	850
23	23	Larix	Larix griffithiana	Himali salla	510
24	24	Litsea	spp	NA	610
25	25	Michelia	Michelia champaca	Champ	497
26	26	Myrica	Myrica esculenta	Kafal	750
27	27	Pinus	Pinus roxburghii	Chir Pine	650
28	28	Pinus	Pinus wallichiana	Blue Pine	400
29	29	Quercus	Quercus floribunda	NA	860
30	30	Quercus	Quercus lamellosa	Thulo Phalant	860
31	31	Quercus	Quercus lanata	Banjh	860
32	32	Quercus	Quercus leucotrichophora	Tikhe Banjh	860
33	33	Quercus	Quercus semecarpifolia	Khrsu	860
34	34	Quercus	spp	NA	860
35	35	Rhododendron	Rhododendron arboreum	Lali gurans	640
36	36	Schima	Schima wallichii	Chilaune	689
37	37	Shorea	Shorea robusta	Sal	880
38	38	Syzygium	spp	NA	750
39	39	Terminalia	Terminalia tomentosa	Asna	950
40	40	Trewia	Trewia nudiflora	Gutel	352
41	41	Tsuga	Tsuga dumosa	Hemlock	450
42	42	Terai Miscellenous	Terai hill Miscellenous	Terai hill Miscellenous	674

Annex 5: Branch and Foliage Ratio

ID	No	Genus	Species	Local Name	Definition	bps_repr_pole	bps_small_timber	bps_large_timber	fps_repr_pole	fps_small_timber	fps_large_timber
1	1	Abies	spp	Fir_Assumed same as Pinus wallichiana		0.436	0.372	0.355	0.252	0.142	0.107
2	2	Alnus	Alnus nepalensis	Utis	NA	0.803	1.226	1.51	0.169	0.089	0.06
3	3	Betula	spp	NA	River birch	0.4	0.4	0.4	0.07	0.05	0.04
4	4	Castanopsis	Castanopsis indica	Dhale katus	NA	0.398	0.915	1.496	0.053	0.048	0.042
5	5	Dalbergia	Dalbergia sissoo	Sissoo	NA	0.684	0.684	0.684	0.01	0.01	0.01
6	6	Engelhardtia	Engelhardtia spicata	Mahuwa	NA	0.925	1.41	1.685	0.316	0.225	0.202
7	7	Lyonia	Lyonia ovalifolia	Angeri	NA	0.879	0.709	0.67	0.506	0.714	0.85
8	8	Myrica	Myrica esculenta	Kafal	NA	0.524	0.59	0.605	0.17	0.16	0.155
9	9	Myrsine	Myrsine capitellata	Settee kath	NA	0.4	0.4	0.4	0.07	0.05	0.04
10	10	Phyllantus	Phyllantus emblica	Amala	NA	0.4	0.4	0.4	0.07	0.05	0.04
11	11	Pinus	Pinus roxburghii	Rani salla	NA	0.189	0.256	0.3	0.101	0.046	0.033
12	12	Pinus	Pinus wallichiana	Gobre salla	NA	0.683	0.488	0.41	0.403	0.238	0.18
13	13	Pyrus	Pyrus pashia	Mayal	NA	1.595	2.68	3.22	0.186	0.172	0.169
14	14	Quercus	Quercus lanata	Banjh	NA	0.747	0.96	1.06	0.229	0.215	0.202
15	15	Rhododendron	Rhododendron arboreum	Lali gurans	NA	0.544	0.91	1.135	0.277	0.225	0.212
16	16	Rhus	Rhus wallichii	Thulo Bhalayo	NA	0.601	0.63	0.64	0.143	0.083	0.08
17	17	Schima	Schima wallichii	Chilaune	Schima wallichii	0.52	0.186	0.168	0.064	0.035	0.033
18	18	Shorea	Shorea robusta	Sal	Shorea robusta	0.055	0.341	0.357	0.062	0.067	0.067
19	19	Class1	Mixed and other conifers_assumed same as Pinus roxburghii and Pinus wallichiana			0.4	0.4	0.4	0.07	0.05	0.04
20	20	Class2	Upper slopes Mixed Hardwoods			0.4	0.4	0.4	0.07	0.05	0.04
21	21	Acer	Acer, Betula	NA	NA	0.748	0.986	1.163	0.211	0.184	0.182