**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<br>Vol per ha<br>Top ratio (vol up to 10 cm and 20 cm)<br>Bark ratio | PostGreSQL | Rstudio, Ms Excel |
| 3.7 | | Biomass calculation<br>Mass of stem<br>Mass of foliage<br>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<br>Soil pH<br>Soil NPK analysis<br>Soil organic carbon assessment | Ms Excel | Ms Excel |
| 3.11 | | Forest mapping<br>Forest cover map<br>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 Deforestation and Degradation) 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 ) and Assessing Forest Degradation (handbook).

# 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)*.

**5.10 a. Cross verification of calculated volumes from allometric models**

# to be sure that estimated tree volume is not exceeding the optimum volume that a tree can ever hold

(optimum_volume = BA_tree*USED._HT*0.7)

The logic behind "data_equation <- data_equation %>%, mutate(volume_BA_tree = BA_tree_sqm*USED._HT*0.7)" is unclear as it is not described in FRA_data_analysis_manual_2021.pdf

The number (form factor = **0.7)** used in the script is the maximum value of **form factor for calculating tree volume.**

According to Petrin and Bogdanov (2017)[*Petrin, R., & Bogdanov, K. (2017). Comparative investigations of the form factor for different tree species. Uniform average form factor. Management and Sustainable Development, 63(2), 1-6.*], the form factor of commercial tree species typically ranges from **0.473 to 0.567**. This study provides reliable reference values to minimize the risk of overestimating tree volume when applying allometric equations.

In the context of FRA data analysis, the form factor **0.7** was chosen as a conservative estimate to ensure that the volume calculated using allometric equations does not overestimate the actual volume. This approach is felt as an important step when applying equations developed by Sharma and Pukkala (1990), which were based on a specific range of sample tree diameters at breast height (DBH). When these equations are used for trees with DBH values outside the original sample range (extrapolated values), the volume estimates can deviate significantly.

However, it is important to note that the volume calculated using the form factor-based formula is used only to verify whether the volume calculated from the allometric equation exceeds a reasonable threshold. This step provides an additional layer of validation to ensure that the estimates remain accurate and do not result in inflated volumes due to the extrapolation of DBH values beyond the original dataset.

By employing this conservative form factor, we aim to maintain the reliability of volume estimates while mitigating potential errors from extrapolated data.

**5.10 b. Calculation of final volume**

Volume_final = ifelse (optimum_volume > V, V *volume_ratio, optimum_volume *volume_ratio))

## 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***

## But if the tree is dead,

case I: the tree is dead but still usable, then it is assumed that 75 % of branches still remaining on the tree

case II: the tree is dead and entirely unusable, then it is assumed that 0 % of branches remaining on the tree

The above estimations are based on the consensus of Expert's decision

### 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*

$$f = \left(\frac{n_1}{N}\right) \times 100$$

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 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 2 | 1 | Abies | Abies pindrow | Gobre salla | NA | 5.444 3 | - 2.690 2 | -999 | 0.4 9 | Top Ratio |
| 25 | 2 | 2 | Acacia | Acacia catechu | Khair | NA | 5.440 1 | - 2.491 | -999 | 0.3 9 | Top Ratio |
| 26 | 2 | 3 | Adina | Adina cordifolia | Haldu | NA | 5.468 1 | - 2.439 8 | -999 | 0.5 7 | Top Ratio |
| 27 | 2 | 4 | Albizzia | spp | Sisris | NA | 4.403 1 | - 2.209 4 | -999 | 0.4 6 | Top Ratio |
| 28 | 2 | 5 | Alnus | Alnus nepalensis | Utis | NA | 6.019 | - 2.727 1 | -999 | 0.5 1 | Top Ratio |
| 29 | 2 | 6 | Anogeissus | Anogeissus latifolia | Banjhi | NA | 4.950 2 | - 2.335 3 | -999 | 0.4 1 | Top Ratio |
| 30 | 2 | 7 | Bombax | Bombax malabaricum | NA | NA | 4.555 4 | - 2.300 9 | -999 | 0.5 4 | Top Ratio |
| 31 | 2 | 8 | Cedrela | Cedrela toona | Toon | NA | 4.970 5 | - 2.343 6 | -999 | 0.4 5 | Top Ratio |
| 32 | 2 | 9 | Dalbergia | Dalbergia sissoo | Sissoo | NA | 4.358 | - 2.155 9 | -999 | 0.4 5 | Top Ratio |
| 33 | 2 | 10 | Eugenia | Eugenia jambolana | Jamun | NA | 5.174 9 | - 2.363 6 | -999 | 0.4 4 | Top Ratio |
| 34 | 2 | 11 | Hymanodict yon | Hymanodictyon excelsum | Bhurkul | NA | 5.557 2 | - 2.496 | -999 | 0.5 2 | Top Ratio |
| 35 | 2 | 12 | Lagerstroemi a | Lagerstroemia parviflora | Botdhair o | NA | 5.334 9 | - 2.442 8 | -999 | 0.5 1 | Top Ratio |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 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) |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 7 | 6 | 22 | ClassA | NA | NA | Miscellaneous in Terai | 0.551 | - 0.654 4 | -999 | 0.3 5 | Bark Ratio Top (20cm) |
| 13 8 | 6 | 23 | ClassB | NA | NA | Miscellaneous in Hills | 0.403 1 | - 0.532 1 | -999 | 0.2 2 | Bark Ratio Top (20cm) |
| 4 | 1 | 4 | Albizzia | Albizzia species | Sisris | NA | - 2.428 4 | 1.760 9 | 0.96 62 | 0.1 2 | Total Volume |
| 40 | 2 | 17 | Schima | Schima wallichii | Chilaune | NA | 7.461 7 | - 3.067 6 | -999 | 0.4 4 | 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 (but not limited to…) 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” or “hpred” is created for imputed heights by H-D models.
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=
H_6615<- subset (H,H$H_model=="Sal")

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

ImpFixed_6615<-
  ImputeHeights(H_6615$d,H_6615$h,
        #H_6615$plot_id,
        modelName,level=1,makeplot=TRUE)
summary (ImpFixed_6615$model)
```

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

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

```
# R scripts to handle FRA Nepal data
# Forest Research and Training Centre, Nepal
# Identify individuals and group of species for H-D modeling
# Run pre-existing models in lmfor package by Lauri Mehtatalo
# Generate and impute the predicted heights to all FRA trees
# install.packages(lmfor)
library(tidyverse)
library(readxl)
library(lmfor)
```

```
# import NFI tree_data_2010_2013 DATA name H

H <- read_excel("tree_data_2010_2013.xlsx")

min(H$diameter)
max(H$diameter)

H <- H[H$diameter!="NA",] # just removed 7 plots (7 trees) - no tree data
# just for modeling purposes, we have removed those 7 plots/trees for now

min(H$diameter)
max(H$diameter)

H$d <-as.numeric(H$diameter)

str(H$d)

# add cluster
H$cluster<-(H$col*1000+H$row)   # cluster can be used as grouping factor !!!!

# we need only those trees for which heights in the field are measured
## H$h variable to have only sample trees heights
# -- other tallied trees should have NA in modeling, just to be sure

# H$d<-ifelse(H$diameter>0,H$D, NA)

H$h<-ifelse(H$height_m>0 &
         (H$sample_tree==1 | H$sample_tree==2),
        H$height_m, NA)

str(H$h)

H$h <- as.numeric(H$h)

#### Assign  a model name ####

H$H_model<-ifelse(H$species=="6615", "Shorea",
            ifelse(H$species=="6660", "Terminalia",
                ifelse(H$species=="6651", "Syzygium",
                    ifelse(H$species=="6063", "Acacia",
                        ifelse(H$species=="6089", "Adina",
                            #  ifelse(H$species=="6103" |H$species=="6104" | H$species=="6105", "Albizzia",
                            #     ifelse(H$species=="6106", "Alnus",
                            ifelse(H$species=="6113", "Anogeissus",
                               # ifelse(H$species=="6115", "Aporusa",
                                   # ifelse(H$species=="6126" |H$species=="6127" | H$species=="6131",
"Bauhinia",
                                       #  ifelse(H$species=="6139", "Simal",
                                       ifelse(H$species=="6147", "Buchanania",
                                           ifelse(H$species=="6175" |H$species=="6176" | H$species=="6177",
"Castanopsis",
                                               ifelse(H$species=="6207", "Cleistocalyx",
```

```
ifelse(H$species=="6235" |H$species=="6237" |
H$species=="6239" | H$species=="6240", "Dalbergia",
ifelse(H$species=="6249" |H$species=="6250", "Dillenia",
ifelse(H$species=="6246", "Desmodium",
#  ifelse(H$species=="6256" |
H$species=="6259"|H$species=="6260", "Diospyrus",
#ifelse(H$species=="6335", "Garuga",
ifelse(H$species=="6349", "Hymenodictyon",
ifelse(H$species=="6513", "Pinus",
#ifelse(H$species=="6600"
|H$species=="6602", "Sapium",
ifelse(H$species=="6609", "Schima",
ifelse(H$species=="6369", "Lagerstromia",
ifelse(H$species=="6446", "Miliusa",
# ifelse(H$species=="6370",
"Lannea",
ifelse(H$species=="6419",
"Mallotus",
# ifelse(H$species=="6469",
"Nyctanthes",
ifelse(H$species=="6611",
"Semecarpus",
ifelse(H$species=="6676",
"Trewia",
"Misc"))))))))))))))))))


# Modeling of diameter and height

# par(mfrow=c(1,1))
par(mfrow=c(2,2))

# Out of the following scripts, run only for those species which are present
# in working NFI tree data

# Model name e.g. curtis, naslund, etc. can be changed if required for more accuracy

#### Height model for the species 6660 ( Terminalia) ####

H_Terminalia<- subset (H,H$H_model=="Terminalia")
summary(H_Terminalia)

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

ImpFixed_Terminalia<-
  ImputeHeights(H_Terminalia$d,H_Terminalia$h,
            H_Terminalia$cluster,
            modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Terminalia$model)

H_Terminalia$hpred<-ImpFixed_Terminalia$hpred
```

```
#### Height model for the species 6615 (Shorea robusta Sal) ####

H_Shorea<- subset (H,H$H_model=="Shorea")
names(H_Shorea)
summary(H_Shorea)

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

ImpFixed_Shorea<-ImputeHeights(H_Shorea$d,H_Shorea$h,
                        H_Shorea$cluster,
                        modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Shorea$model)
# H_Shorea$hpred<-ImpFixed_Shorea$hpred
H_Shorea$hpred<-ImpFixed_Shorea$hpred

#### Height model for the species (Anogeissus)####

H_Anogeissus<- subset (H,H$H_model=="Anogeissus")
summary(H_Anogeissus)

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

ImpFixed_Anogeissus<-
  ImputeHeights(H_Anogeissus$d,H_Anogeissus$h,
            H_Anogeissus$cluster,
            modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Anogeissus$model)
H_Anogeissus$hpred<-ImpFixed_Anogeissus$hpred

#### Height model for the species (Buchanania)####

H_Buchanania<- subset (H,H$H_model=="Buchanania")
summary(H_Buchanania)

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

ImpFixed_Buchanania<-
  ImputeHeights(H_Buchanania$d,H_Buchanania$h,
            H_Buchanania$cluster,
            modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Buchanania$model)
H_Buchanania$hpred<-ImpFixed_Buchanania$hpred

#### Height model for the species (Mallotus)####

H_Mallotus<- subset (H,H$H_model=="Mallotus")
summary(H_Mallotus)

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

```
ImpFixed_Mallotus<-
  ImputeHeights(H_Mallotus$d,H_Mallotus$h,
          H_Mallotus$cluster,
          modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Mallotus$model)
H_Mallotus$hpred<-ImpFixed_Mallotus$hpred

#### Height model for the species (Lagerstromia)####

H_Lagerstromia<- subset (H,H$H_model=="Lagerstromia")
summary(H_Lagerstromia)

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

ImpFixed_Lagerstromia<-
  ImputeHeights(H_Lagerstromia$d,H_Lagerstromia$h,
          H_Lagerstromia$cluster,
          modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Lagerstromia)
H_Lagerstromia$hpred<-ImpFixed_Lagerstromia$hpred

#### Height model for the species (Dalbergia)####

H_Dalbergia <- subset (H,H$H_model=="Dalbergia")
summary(H_Dalbergia)

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

ImpFixed_Dalbergia<-
  ImputeHeights(H_Dalbergia$d,H_Dalbergia$h,
          H_Dalbergia$cluster,
          modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Dalbergia)
H_Dalbergia$hpred<-ImpFixed_Dalbergia$hpred

#### Height model for the species (Trewia)####

H_Trewia<- subset (H,H$H_model=="Trewia")
summary(H_Trewia)

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

ImpFixed_Trewia<-
  ImputeHeights(H_Trewia$d,H_Trewia$h,
          H_Trewia$cluster,
          modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Trewia)
H_Trewia$hpred<-ImpFixed_Trewia$hpred
```

```
#### Height model for the species (Adina)####

H_Adina<- subset (H,H$H_model=="Adina")
summary(H_Adina)

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

ImpFixed_Adina<-
  ImputeHeights(H_Adina$d,H_Adina$h,
               H_Adina$cluster,
               modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Adina)
H_Adina$hpred<-ImpFixed_Adina$hpred

#### Height model for the species (Cleistocalyx)####

H_Cleistocalyx<- subset (H,H$H_model=="Cleistocalyx")
summary(H_Cleistocalyx)

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

ImpFixed_Cleistocalyx<-
  ImputeHeights(H_Cleistocalyx$d,H_Cleistocalyx$h,
               # H_Cleistocalyx$cluster,
               modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Cleistocalyx$model)
H_Cleistocalyx$hpred<-ImpFixed_Cleistocalyx$hpred

#### Height model for the species (Dillenia)####

H_Dillenia<- subset (H,H$H_model=="Dillenia")
summary(H_Dillenia)

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

ImpFixed_Dillenia<-
  ImputeHeights(H_Dillenia$d,H_Dillenia$h,
               H_Dillenia$cluster,
               modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Dillenia$model)
H_Dillenia$hpred<-ImpFixed_Dillenia$hpred

#### Height model for the species 6651 ( Syzygium) ####

H_Syzygium<- subset (H,H$H_model=="Syzygium")
summary(H_Syzygium)

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

```
ImpFixed_Syzygium<-
  ImputeHeights(H_Syzygium$d,H_Syzygium$h,
             H_Syzygium$cluster,
             modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Syzygium)
H_Syzygium$hpred<-ImpFixed_Syzygium$hpred

#### Height model for the species (Castanopsis)####

H_Castanopsis<- subset (H,H$H_model=="Castanopsis")
summary(H_Castanopsis)

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

ImpFixed_Castanopsis<-
  ImputeHeights(H_Castanopsis$d,H_Castanopsis$h,
             # H_Castanopsis$cluster,
             modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Castanopsis$model)
H_Castanopsis$hpred<-ImpFixed_Castanopsis$hpred

#### Height model for the species (Desmodium)####

H_Desmodium<- subset (H,H$H_model=="Desmodium")
summary(H_Desmodium)

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

ImpFixed_Desmodium<-
  ImputeHeights(H_Desmodium$d,H_Desmodium$h,
             H_Desmodium$cluster,
             modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Desmodium$model)
H_Desmodium$hpred<-ImpFixed_Desmodium$hpred

#### Height model for the species (Semecarpus)####

H_Semecarpus<- subset (H,H$H_model=="Semecarpus")
summary(H_Semecarpus)

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

ImpFixed_Semecarpus<-
  ImputeHeights(H_Semecarpus$d,H_Semecarpus$h,
             H_Semecarpus$cluster,
             modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Semecarpus$model)
H_Semecarpus$hpred<-ImpFixed_Semecarpus$hpred
```

```
#### Height model for the species (Pinus)####

H_Pinus<- subset (H,H$H_model=="Pinus")
summary(H_Pinus)

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

ImpFixed_Pinus<-
  ImputeHeights(H_Pinus$d,H_Pinus$h,
             H_Pinus$cluster,
             modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Pinus)
H_Pinus$hpred<-ImpFixed_Pinus$hpred

#### Height model for the species 6663 (Acacia)####

H_Acacia<- subset (H,H$H_model=="Acacia")
summary(H_Acacia)

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

ImpFixed_Acacia<-
  ImputeHeights(H_Acacia$d,H_Acacia$h,
            # H_Acacia$cluster,# because too low samples if cluster taken
             modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Acacia)
H_Acacia$hpred<-ImpFixed_Acacia$hpred

#### Height model for the species (Hymenodictyon)####

H_Hymenodictyon<- subset (H,H$H_model=="Hymenodictyon")
summary(H_Hymenodictyon)

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

ImpFixed_Hymenodictyon<-
  ImputeHeights(H_Hymenodictyon$d,H_Hymenodictyon$h,
             H_Hymenodictyon$cluster,
             modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Hymenodictyon$model)
H_Hymenodictyon$hpred<-ImpFixed_Hymenodictyon$hpred

#### Height model for the species (Schima)####

H_Schima<- subset (H,H$H_model=="Schima")
summary(H_Schima)

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

ImpFixed_Schima<-
```

```
  ImputeHeights(H_Schima$d,H_Schima$h,
            # H_Schima$cluster,
             modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Schima)
H_Schima$hpred<-ImpFixed_Schima$hpred

#### Height model for the species (Miliusa) ####

H_Miliusa<- subset (H,H$H_model=="Miliusa")
summary(H_Miliusa)

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

ImpFixed_Miliusa<-
  ImputeHeights(H_Miliusa$d,H_Miliusa$h,
             H_Miliusa$cluster,
             modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Miliusa)
H_Miliusa$hpred<-ImpFixed_Miliusa$hpred

# modeling of individual tree species ends here


# modeling of other tree species as "Miscellaneous"
#### Height model for the species (Misc)####

H_Misc<- subset (H,H$H_model=="Misc")
summary(H_Misc)

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

ImpFixed_Misc<-
  ImputeHeights(H_Misc$d,H_Misc$h,
             H_Misc$cluster,
             modelName,level=0,makeplot=TRUE)

summary (ImpFixed_Misc)
H_Misc$hpred<-ImpFixed_Misc$hpred

#### Combine all Predicted Height####

list_H_models <- str_subset(ls(), pattern = "H_")

combined_pred_ht <- bind_rows(mget(list_H_models))

write.csv(combined_pred_ht, file = "tree_data_2010_2013_with_pred_heights.csv",row.names = F)

# Modeling ends...
```

## 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 |

For Miscellaneous species, we used 674 and its detail clarifications are in an excel file "Denisty Clarification.xlsx": https://docs.google.com/spreadsheets/d/197-519-DYs_HipuC-VV5xeKfjrCd-r84/edit?gid=1282810174#gid=1282810174

## 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 |