ICIMOD Working Paper 2016/6

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FOR MOUNTAINS AND PEOPLE

Assessment of Forest Carbon Stock and Carbon Sequestration Rates at the ICIMOD Knowledge Park at Godavari

NORWEGIAN MINISTRY OF FOREIGN AFFAIRS

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The International Centre for Integrated Mountain Development, ICIMOD, is a regional knowledge development and learning centre serving the eight regional member countries of the Hindu Kush Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalization and climate change have an increasing influence on the stability of fragile mountain ecosystems and the livelihoods of mountain people. ICIMOD aims to assist mountain people to understand these changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues. We support regional transboundary programmes through partnership with regional partner institutions, facilitate the exchange of experience, and serve as a regional knowledge hub. We strengthen networking among regional and global centres of excellence. Overall, we are working to develop an economically and environmentally sound mountain ecosystem to improve the living standards of mountain populations and to sustain vital ecosystem services for the billions of people living downstream – now, and for the future.

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Acronyms and Abbreviations

AGTB	aboveground tree biomass
ANSAB	Asia Network for Sustainable Agriculture and Bioresources
AGSB	aboveground sapling biomass
BGB	belowground biomass
cc	cubic centimeter
CHAL	Chitwan Annapurna Landscape
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
Cm (or CM)	Centimetre
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COP	Conference of Parties
DBH (or dbh)	diameter at breast height
DFRS	Department of Forest Research and Survey
FAO	Food and Agriculture Organization
FECOFUN	Federation of Community Forestry Users Nepal
FRA	Forest Resource Assessment
g	gram
GIS	geographical information system
GPS	global positioning system
ha	hectare
ICIMOD	International Centre for Integrated Mountain Development
IKM	Integrated Knowledge Management
InFEWS	Integrated Forest Ecosystem and Watershed Services
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
LHG	leaf litter, herbs and grass
LU	land use
m	meter
masl	metres above sea level
MFSC	Ministry of Forests and Soil Conservation
MENRIS	Mountain Environmental Natural Resources Information Systems
mm	millimetre
QA	quality assurance
QC	quality control
REDD	Reducing emissions from deforestation and forest degradation
REDD+	Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
SALT	Sloping Agricultural Land Technology
SOP	standard operating procedures
SOC	soil organic carbon
t	tonne
TAL	Terai Arc Landscape
tC	tonne carbon
TISC	Tree Improvement and Silviculture Component
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNIQUE	UNIQUE Forestry and Land Use GmbH, Germany
VDC	village development committee
WWF	World Wildlife Fund

Acknowledgements

This report presents a comprehensive assessment of forest carbon stock and sequestration rates, as well as the current status and potential of carbon stock storage in the protected mountain forests of the ICIMOD Knowledge Park at Godavari, Kathmandu. The study was conducted by an independent team of consultants and ICIMOD under the REDD+ Himalaya Initiative with support from the Norwegian Ministry of Foreign Affairs.

The study was accomplished through the generosity and support of David Molden, Anja Møller Rasmussen, and the ICIMOD Knowledge Park Committee. Without their support and encouragement, this study would not have been possible. We would like to express our gratitude to the National Agriculture Research Council for supporting us in testing the soil organic carbon. We acknowledge Padam Raj Joshi, Jay Raj Mishra, Deepak Charmakar, and Rupesh KC for helping the team undertake the forest carbon inventory and collect the field data. Thanks are due to Knowledge Park team members – Jeevan Tamang, Purna Thapa, Saila Tamang, Padam Bahadur Tamang, Som Bahadur Tamang, Santa Bahadur Tamang, Vijaya Tamang, and Kaktung Tamang – who were actively involved in the forest inventory and data collection.

Part of the study included training staff of the ICIMOD Knowledge Park in forest carbon measurement, which, together with the field work, added value by developing local resource persons. We would like to thank these local resource persons and hope the trainings will prove useful in similar types of work in the future.

Executive Summary

Forests store about 80% of all aboveground and 40% of all belowground terrestrial organic carbon, making forest ecosystems crucial to maintaining the global carbon balance and mitigating climate change (IPCC 2001). Forest carbon sequestration is a measure that can be taken up to mitigate climate change. But the amount of carbon stored in forests differs according to spatial and temporal factors such as forest type, size, age, stand structure, associated vegetation, and ecological zonation, among other things. Forest management and associated silviculture treatments are key determinants of forest carbon dynamics. Vegetation, along with associated soil types, are viable sinks and are making significant contributions to sequestering atmospheric carbon, thus mitigating the impacts of climate change. To quantify the amount of carbon sequestered in a forest ecosystem, temporal stocks of carbon within various forest strata need to be assessed.

This study presents the results of carbon assessment of protected forests at the International Centre for Integrated Mountain Development (ICIMOD) Knowledge Park at Godavari. In addition to updating the baseline carbon stock measured in 2012, this 2014 carbon stock assessment provided hands-on training to local resource persons. This will be helpful in the future when additional data has to be collected and for showcasing carbon monitoring techniques and sequestration rates to visitors to the Knowledge Park.

A total of 20 permanent sample plots (18 in dense strata and two in sparse strata) established in 2012 were re-measured in 2014 using the methodology set out in the 'Forest Carbon Measurement Guidelines 2010' (ICIMOD et al. 2010). These guidelines were developed by ICIMOD and its consortium partners – Asia Network for Sustainable Agriculture and Bioresources (ANSAB) and Federation of Community Forestry Users Nepal (FECOFUN) – who implemented a REDD+ pilot project in three watersheds of Nepal from 2009 to 2013. Carbon was measured from five carbon pools: aboveground biomass; belowground biomass; regeneration; leaf, herbs, and grass; and soil organic carbon. A 500 m^2 nested plot with a 12.62 m radius was set up for tree inventories. Sapling data was recorded from a 5.64 m radius plot. Sample data on regeneration was collected from a nested sub-plot of 1 m radius. In addition, leaf litter, herbs, grass, and soil samples were collected from a nested sub-plot of 0.56 m radius. Belowground biomass was estimated with a default value (20% of aboveground biomass). Total biomass was converted to carbon stock using the default value (0.47) suggested by the Intergovernmental Panel on Climate Change (IPCC 2006). Furthermore, quality assurance and quality control were maintained through regular monitoring to ensure that reliable field measurements were collected, to verify laboratory procedures, and to verify data entry and analysis techniques. The data analysis was carried out using Microsoft Excel and R software environment, after which it was presented in a tabular form as well as in diagrams and figures.

The study found that there was an increase in carbon stock from 263.44 tC ha^{-1} (i.e., 966.68 tCO_2e) in 2012 to 269.22 tC ha^{-1} (i.e., 988.04 tCO_2e) in 2014, making the annual sequestration rate equivalent to 2.65 tC ha^{-1} yr^{1} (i.e., 10.68 tCO_2e). The total forest carbon available in the ICIMOD Knowledge Park in 2012 was 7,903 tonnes (29,004.74 tCO_2e), which increased to 8,076.6 tonnes (29,641.12 tCO_2e) in 2014. This resulted in a total of 640.8 tCO_2e being sequestered by the forest at the Knowledge Park in 2014.

In the future, regular monitoring of the forest carbon plots is recommended to assess changes in the stock and fluxes of forest carbon and other ecosystem services generated by the protected forest in the Knowledge Park. The local resource persons trained during the carbon assessment in 2014 can be engaged to conduct on-site demonstrations for visitors, students, and researchers to the Knowledge Park. The results and information generated by this study will also be distributed through leaflets and updated on ICIMOD's online geoportals. A methodology for wider dissemination, including partner training, must be explored under ICIMOD's regional programmes, particularly those working in transboundary landscapes.

Introduction

Forest ecosystems provide a number of provisioning, regulatory, supporting, and cultural services that are important to the lives and livelihoods of humans, and they also play an important role in maintaining habitats that support important global biodiversity (Raich et al. 2014; Escobedo et al. 2011). Compared to other terrestrial ecosystems, forests store the most carbon (Pan et al. 2011), with the majority of sequestered carbon held in woody biomass (Scott et al. 2004). Because of this, forests can also play a vital role in global climate change mitigation (Miller et al. 2007). Trees lock atmospheric carbon dioxide in the form of carbon, and hence reduce atmospheric greenhouse gas (GHG) accumulation. However, the availability of the valuable goods and services that forests provide is decreasing as a result of deforestation and forest degradation. Addressing deforestation and forest degradation in developing countries, where these activities are largely related to population growth rates and over-exploitation for fuel and export (Allen and Barnes 1985), is a formidable challenge.

Deforestation and forest degradation influence the amount of carbon in the atmosphere, with deforestation and forest degradation contributing an estimated 18% of total global anthropogenic greenhouse gas emissions (Stern Review 2007). However, recent estimates of global carbon emissions from 2011 to 2015 point to a 25% reduction in emissions resulting from deforestation and forest degradation (i.e., from an annual average of 3.9 billion tonnes of CO2 in 2011 to 2.9 billion tonnes in 2015). This drop is linked to net growth in planted forest (FAO 2015).

In Nepal, a forest inventory conducted by the Department of Forest Research and Survey (1999) estimated the nation's total forested area to be around 40% (29% forest cover and 11% shrubland), with an annual deforestation rate of 1.7% from 1978 to 1994. The Food and Agriculture Organization of the United Nations estimated the deforestation rate in Nepal between 1990 and 2005 to be 1.63% per year (FAO 2005, 2010), and the average deforestation rate in the southern plains of the Terai from 1991 to 2001 was estimated to be 2.7% (Central Bureau of Statistics 2008). These data validate the shrinking of forest cover over the last four decades, as found in a study by Acharya and Dangi (2012). In contrast, some studies in the middle hills found an increase in forest cover, particularly after the expansion of community forestry (Branney and Yadav 1998; Gautam et al. 2003; Carter et al. 2011). With 35 forest types, 75 vegetation types, and 118 ecosystem types (MOFSC 2002), deforestation and forest degradation in Nepal is a diverse and complex issue. Nepal's Ministry of Forests and Soil Conservation has identified nine drivers of deforestation and degradation: high dependency on forests and forest products (timber, fuelwood, and other non-timber forest products); illegal harvesting of forest products; unsustainable harvesting practices; forest fires; encroachment; overgrazing; infrastructure development; resettlement; and the expansion of invasive species. The sustainable management of forests is essential to addressing these drivers of deforestation and forest degradation, reducing pressure on forests, and promoting biodiversity conservation.

The amount of carbon stored in forests differs according to spatial and temporal factors such as forest type, size, age, stand structure and associated vegetation and ecological zonation (Raich et al. 2014; Escobedo et al. 2011; Ma et al. 2014). Understanding these differences, and how they affect the degree to which the effects of green house gas (GHG) emissions can be offset through afforestation and improved forest management, is important to informing forestry management programmes (Paoletti 2009; Zhao et al. 2010).

In 2014, a study of the forest in the ICIMOD Knowledge Park at Godavari was conducted to better understand carbon dynamics of the forest, and to update the forest carbon stock data against measurements taken in 2012 – the first time such a study was conducted in the area. The study also created opportunities to provide on-site demonstrations of forest carbon measurements and associated information to the local community forest user group.

The ICIMOD Knowledge Park

The ICIMOD Knowledge Park at Godavari, located on the southern slopes of the Kathmandu Valley, was set up in March 1993, following the generous provision of 30 hectares of land by His Majesty's Government of Nepal in November 1992. Given ICIMOD's central mandate to help promote the development of an economically and environmentally sound mountain ecosystem and to improve the living standards of mountain populations in the HKH, the site provides a practical pendant to the practice on the ground. Different technologies and practices useful for sustainable development are tested, selected, and demonstrated.

At the time it was handed over, a large part of the site was heavily degraded, and initial activities focused on the rehabilitation of degraded land systems. Since then, a considerable part of the degraded forest and shrubland has been gradually restored to semi-natural forest. All plants are grown without the application of inorganic fertilizers or pesticides. The number of approaches being tested and demonstrated in the Knowledge Park has increased over time, covering different aspects required for an integrated approach to mountain development and agriculture. Present day activities focus on vegetation management; soil management; water management; income-generation through high value cash crops, horticulture, and beekeeping; livestock management; biodiversity conservation; renewable energy technologies; community outreach/off-site demonstration, training, and provision of materials; scientific research; and training and dissemination.

From May to July 2012, a carbon stock assessment of the park was conducted to quantify the carbon sequestered by naturally regenerated trees. A total of 20 (18 dense and two sparse) permanent sample carbon monitoring plots were established and measured as a baseline for the periodic biomass and carbon assessment. Forest carbon stock varies according to forest type/structure, associated vegetation, standage, ecological zonation, and several other ecological factors. Forest management activities and associated silvicultural treatments are key determinants of forest carbon dynamics. The baseline study reported that the average weighted carbon per hectare was 263.44 tonnes in the forests of the ICIMOD Knowledge Park (ICIMOD 2012).

Objectives

The general objective of this research was to monitor forest carbon stock and assess carbon sequestration rates in the forests of the ICIMOD Knowledge Park at Godavari, Kathmandu. The specific objectives were to:

- Assess forest carbon stock in the ICIMOD Knowledge Park
- Monitor and update changes in forest carbon stock and carbon sequestration rates in the forests for better management of forest ecosystems of the ICIMOD Knowledge Park
- Provide methodology and on-site demonstrations to visitors including students, farmers, and decision makers to enhance understanding of the role that forests play in mitigating climate change

The research findings and results can also be compared with similar carbon data generated by other studies in community and state-managed forests in Nepal. The rationale for this research was to collect data and information, not only to serve as a statistically valid estimation of forest biomass and carbon stock with prescribed silvicultural treatments in the given site, but also to assess the potential of natural forest vegetation to sequester atmospheric carbon under a 'business as usual' scenario and, thereby, assist with predicting the biomass, carbon stock, and sequestration rates of natural vegetation in similar places at national and sub-national levels.

Overview of the Research Site

Site description

The research site lies in the Pulchowki watershed area in the southeast corner of the Kathmandu Valley, about 15 km away from Kathmandu city. It lies within the ICIMOD Knowlede Park at Godavari, which was established as a demonstration and training centre by ICIMOD in 1993 and falls under the administrative jurisdiction of the Godavari Village Development Committee (VDC), Ward No. 5, Lalitpur District. The geographical coordinates are latitude 30°53'050" N and 30°53'570" N and longitude 83°75'50" E. The site sits between altitudes of 1,510 and 1,780 m, with a slope gradient that ranges from almost zero degrees up to more than 60 degrees in parts of the upper forest zone. The soil varies from clayey loam to sandy and silty clayey loam that is rich in forest humus, and from stream bed sandy alluvial soil to ridge top shallow dry soil. The Knowledge Park is about 30 hectares in area and is surrounded by the Godavari Kunda Community Forest to the northeast and Diyale Community Forest to the southwest (Figure 1).

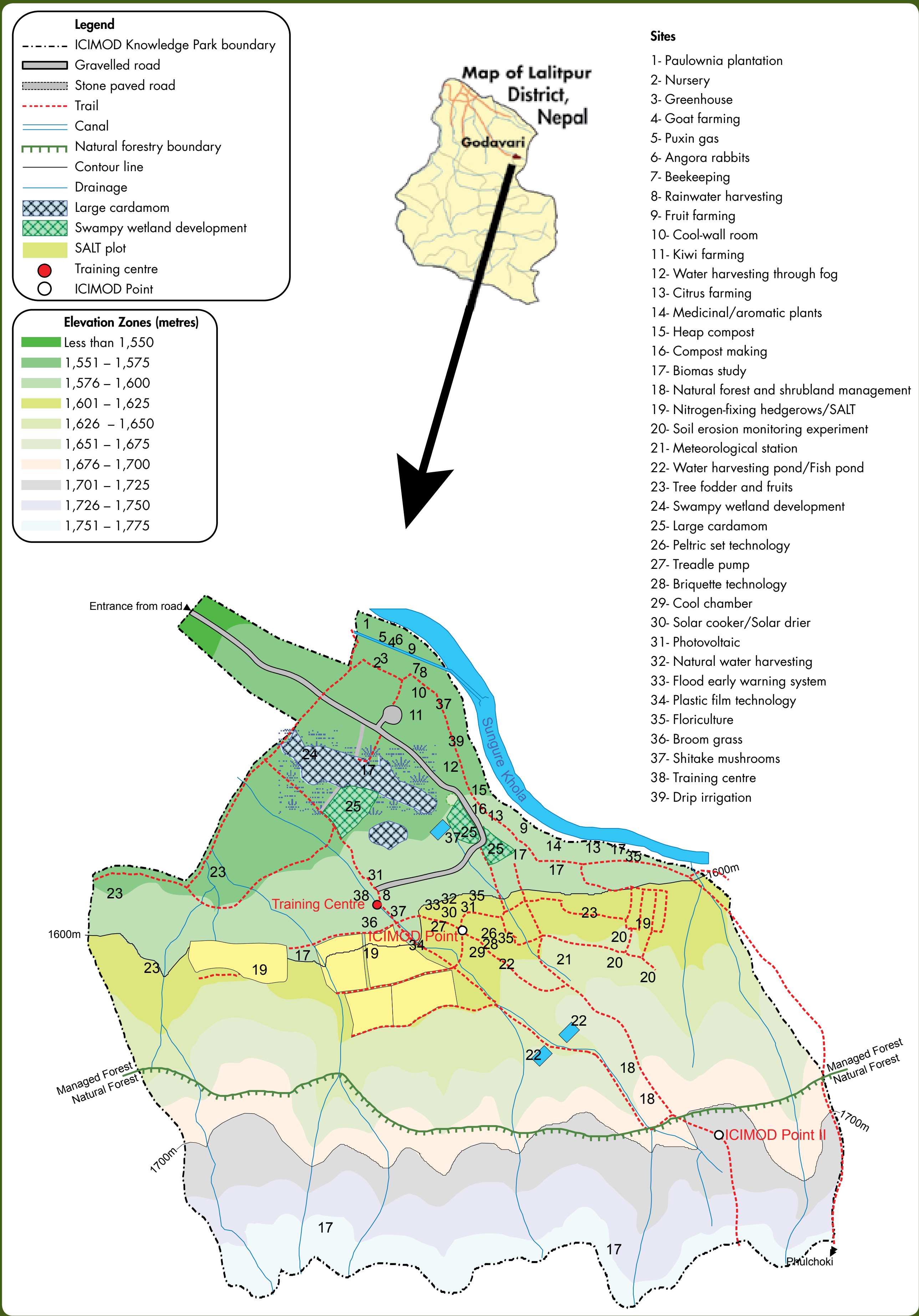
Climate

The climate at the site is warm-temperate and subtropical, with a mean annual temperature of 17.2°C. The maximum summer temperature is 33.8°C, whereas the minimum winter temperature is -0.9°C. The relative humidity is 76%. Most of the precipitation occurs during the monsoon and the average annual rainfall is about 2,000 mm.

Vegetation and forest types

The natural forests at the research site were previously dominated by *Schima wallichii* spp., *Castanopsis species*, *Michelia* spp., *Alnus nepalensis*, *Rhododendron arboreum*, and *Litsea oblonga,* which were destroyed through continuous and excessive use for fodder, fuelwood, timber, and charcoal-making and frequent forest fires. The existing forest comprises almost all naturally regenerated tree species, and is dominated by mixed deciduous and evergreen broadleaf species. The current vegetation cover shows natural forest on steep slopes (mainly *Carpinus*, *Castanopsis* spp. and *Anrundinaria*, *Quercus* spp., *Michelia* spp., and *Schima wallichii*), shrub land on mixed slopes (mainly *Cleyera*, *Laurel*, *Quercus*, *Alnus*, *Castanopsis*, and *Schima* spp.), and shrubs and bushes on the valley floor (*Rubus*, *Xylosam*, *Eupatorium*, scattered *Pinus* spp., *S. wallichii*, *Michelia*, *Alnus*, and *Castanopsis* spp.).

Figure 1: **Research site at the ICIMOD knowledge park**



Methodology

Forest carbon accounting approaches

There are two fundamentally different, but equally valid and globally accepted, approaches to estimating forest carbon stock changes: the stock-based or stock-difference approach and the process-based or gain-loss approach (Good Practice Guidelines; IPCC 2006). These approaches can be used to estimate stock changes in any carbon pool. The stock-based approach estimates the difference in carbon stocks in a particular pool at two different points in time. This approach is used when carbon stocks in relevant pools have been measured and estimated over time, such as in national forest inventories. The process-based or gain-loss approach estimates the net balance of additions to and removals from a carbon pool. Gains in the living biomass pool result from vegetation growth, while gains in other pools result from carbon transfer from another pool (e.g., transfer from a biomass pool to a dead organic matter pool due to disturbance). Similarly, losses result from carbon transfer to another pool and emissions due to harvesting, decomposition, or burning. This method is used when annual data such as biomass growth rates and wood harvests are available. The present study used the stock-difference approach, which is considered a reliable, easy, and cost-effective method for estimating changes in forest carbon stock over a given time period in different pools in natural forests.

The Forest Carbon Measurement Guideline 2010 (Subedi et al. 2010), developed by ICIMOD, ANSAB and FECOFUN for the Norad REDD+ pilot project (from 2009 to 2013), was followed to undertake the field inventory (ICIMOD et al. 2010). The analyses were performed using Microsoft Excel, SPSS 19.0, and R-statistical software (R Development Core Team 2009).

Sampling design

The nested plot method suggested by Ravindranath and Ostwald (2008) was used in the sampling design because of its simplicity for long-term monitoring. The sampling design is briefly described in the following sections.

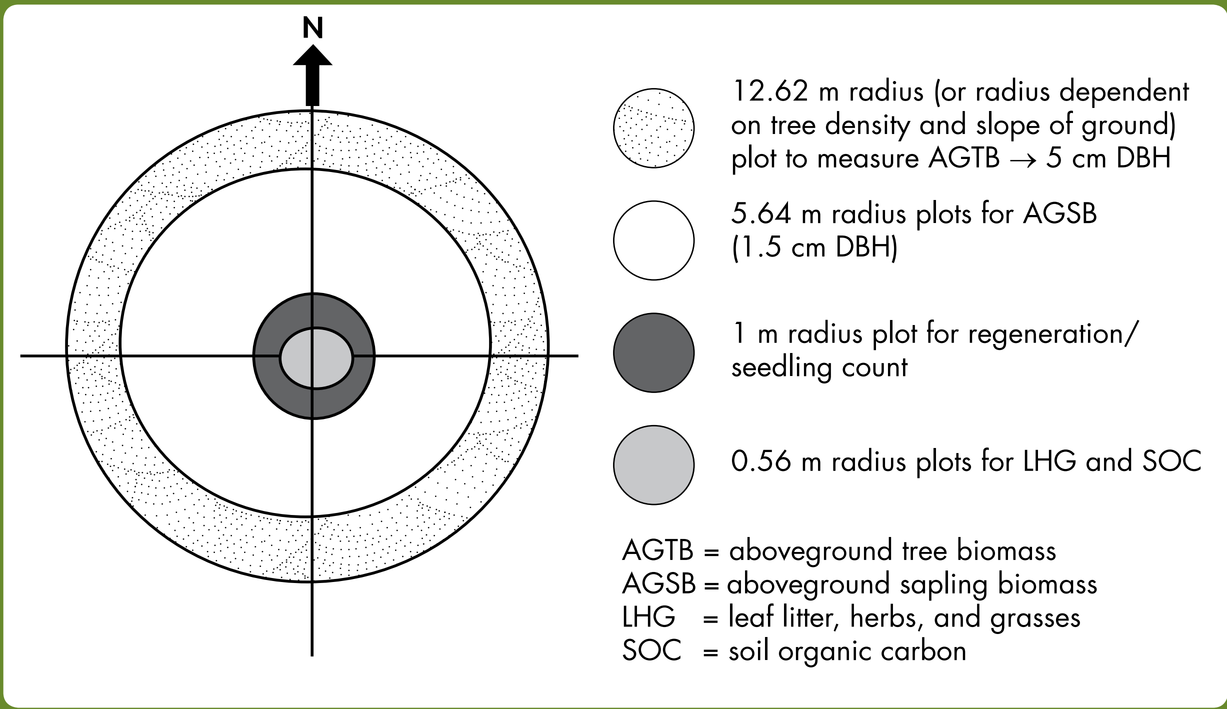
Delineation of forest boundary and forest stratification

A participatory resource map of the protected forest at Godavari was prepared with the help of a GIS expert from ICIMOD and local people familiar with the important characteristics of the forest, such as species distribution, age, class, and crown density. The forest boundary was mapped using a global positioning system (GPS) and ArcGIS software. For this, the entire forest boundary was visited during the baseline year (2012) and respective coordinates were marked. Later, the whole forest was divided into two main strata: sparse (less than 70% crown canopy) and dense (more than 70% crown canopy) using ArcGIS software with high resolution remote sensing images, ERDAS Imagine, and Definiens Developer.

Design of nested circular plots

As shown in Figure 2, concentric nested circular plots were used for the forest carbon inventory to simplify the sampling design, especially on sloping terrain. This design also minimizes edge effects, which usually occur in rectangular plots. A circular plot of 500 m^2 with a 12.62 m radius was set up to measure the trees, while an additional nested plot of 100 m^2, with a 5.64 m radius, was established for sapling measurement. Likewise, a plot with a 1 m radius was used to count regeneration/seedlings and another plot of 0.56 m radius was set up to collect LHG samples and soil samples. Slope correction was made in each permanent plot simultaneously whenever required.

Figure 2: **Sampling design**



Permanent plot distribution and layout

A total of 20 permanent plots were established within two different forest strata (i.e. 18 permanent sample plots in dense strata and two in sparse strata) for the forest carbon inventory in the protected forests at the ICIMOD Knowledge Park. The plots were randomly distributed using Hawth's analysis tools for ArcGIS (www.spatialecology.com). The GPS coordinates (Annex I) were loaded onto a GPS set (GPSMAP 62s e 62st, Garmin) indicating a centre of the nested concentric plots. Later the plots were navigated with the help of the GPS and a centre point was fixed at for each plot in the field (see Figure 3).

Measurement of forest carbon pools

Three forest carbon pools including aboveground (trees, saplings and leaf litter, herb and grass), belowground biomass, and soil organic carbon pools were re-measured in 2014 against the baseline year 2012 (Figure 4). The details of field measurement techniques and methods for estimating forest carbon stock for these different pools are described in the following sections.


Photo 1: Forest technician measuring tree DBH

Aboveground tree biomass

The diameter at breast height (DBH) of trees standing at least a 1.3 m, and the height of individual trees greater than or equal to 5 cm DBH were measured in 20 permanent circular plots (each 500 m^2 in area) (Photo 1). The DBH was measured using a diameter tape whereas a Vertex-IV and a Transponder were used for height measurement (Photo 2). Trees were marked starting from the northern edge and working inwards to prevent accidental double counting. Each tree was

Figure 3: **Permanent sample plots distributed on a base map**

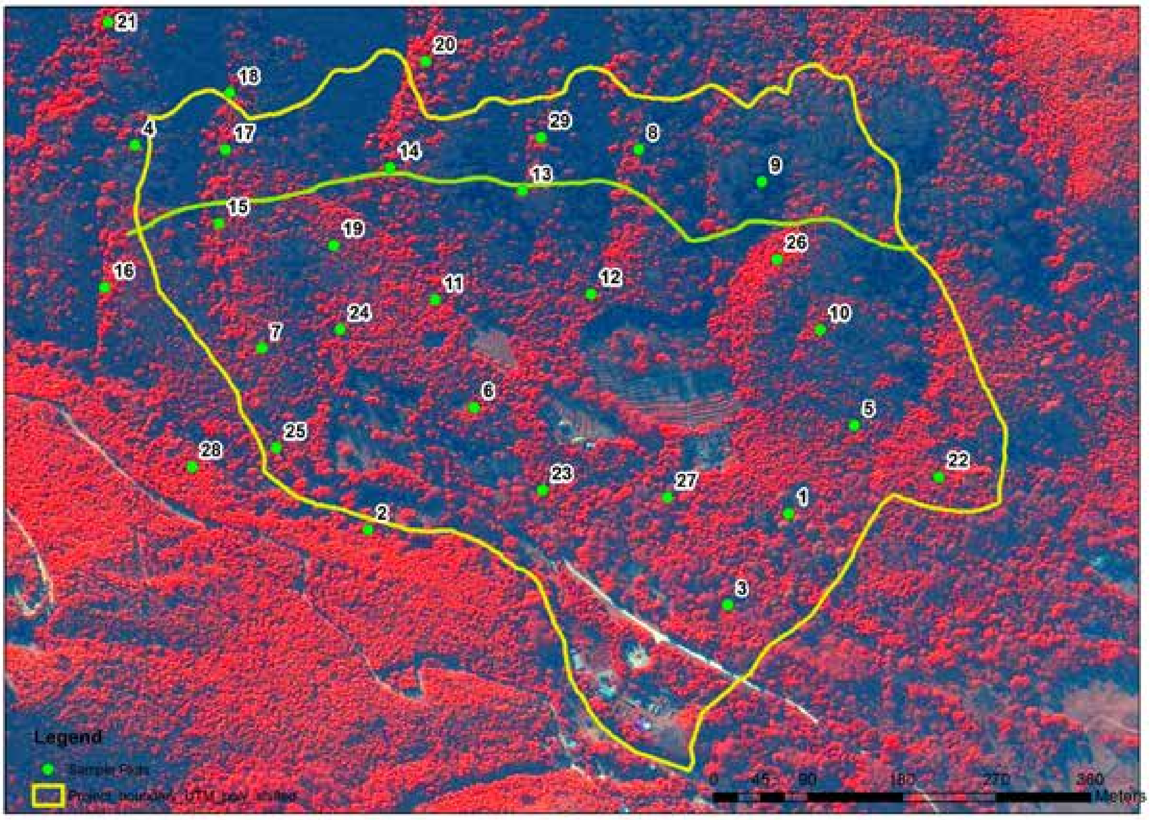


Figure 4: **Forest carbon pools**

- **Aboveground biomass**
  - Trees
  - Saplings
  - Leaf litter, herbs and grasses
- **Belowground biomass**
- **Soil organic carbon**

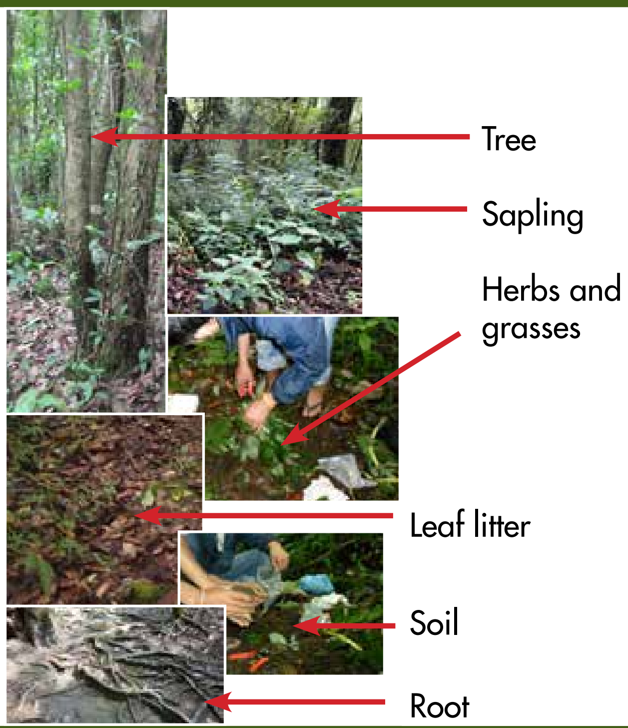


Photo 2: Tree height measurment using Vertex IV

then recorded individually along with its species classification. Trees on the border were only included if more than 50% of their basal area fell within the plot, otherwise they were excluded from the inventory.

To calculate the aboveground tree biomass, we considered the ecological condition of the forest and adopted a biomass equation developed for a moist forest stand suggested by Chave et al. (2005, p 93).

$$AGTB = 0.0509 * \rho D^2 H \quad (1)$$

where,

$AGTB$ = aboveground tree biomass [kg]
ρ = wood-specific density [kg m^{-3}]
D = tree diameter at breast height (DBH) [cm]
H = tree height [m]

For different tree species the value of wood-specific density (ρ) was used, as mentioned in the Master Plan for the Forestry Sector (Ministry of Forests and Soil Conservation 1988). However, for those species without a wood-specific density value, a general value was used according to the associated forest types (see Annex II).

The biomass stock (kg m^{-2}) of each sampling plot was obtained by dividing the sum of all the individual biomass weights (in kilogrammes) by the area of the sampling plot (500 m^2). This AGTB value was converted to tonnes per hectare upon multiplying by 20 (Annex VI). Later, biomass value was converted into carbon stock and carbon dioxide equivalent (CO_2e) upon multiplying by the default carbon fraction of 0.47 (IPCC 2006) and 3.67 (Pearson et al. 2007), respectively.

Aboveground sapling biomass

Saplings with a diameter >1 cm to <5 cm a height of at 1.3 m aboveground were measured in a nested sub-plot with a 5.64 m radius. A national allometric biomass equation developed by the Department of Forest Research and Survey and the Department of Forests', Tree Improvement and Silviculture Component (Tamrakar 2000) was applied to determine the AGSB. For tree species other than those listed in the biomass table, biomass equations were applied according to the given associations of species (forest type). The following regression model was used for an assortment of species to calculate the biomass (Annex VII).

$$Log\ (AGSB) = a + b\ Log\ (D) \quad (2)$$

where,

Log = natural log (dimensionless)
AGSB = aboveground sapling biomass [kg]
a = intercept of allometric relationship for saplings (dimensionless)
b = slope allometric relationship for saplings (dimensionless
D = diameter at breast height (1.3 m aboveground)

The variables (i.e., a and b) used for all tree species are presented in Annex VII. Later, the calculated biomass stocks were converted to carbon stocks using the IPCC (2006) default carbon fraction of 0.47.

Seedling/regeneration count

The status of forest regeneration was evaluated within a nested plot of 1 m radius. Seedlings with <1 m height were accounted for, identified, and recorded in a field book.

Leaf litter, herbs, and grass biomass

All litter (dead leaves, twigs, etc.) and live components (herbs and grass) on the forest floor were collected separately in a destructive manner from a nested sub-plot of 0.56 m radius (Photos 3 and 4). The fresh weight of each item was recorded within 0.1 g precision. Then, a well-mixed sub-sample of about 100 g was wrapped in a marked bag and transported to the National Agriculture Research Council's laboratory for calculating oven dry weight/mass. Later, the amount of biomass per unit area was calculated using the following equation:

$$LHG = \frac{w_{field}}{A} * \frac{w_{subsample,\ dry}}{w_{subsample,\ wet}} \times 10{,}000 \qquad (3)$$

where,

LHG = biomass of leaf litter, herb and grass [t ha^{-1}]

W_{field} = weight of the fresh field sample of leaf litter, herb and grass, destructively sampled within an area of size A [g]

A = size of the area in which leaf litter, herbs, and grass were collected [m^2]

$W_{subsample,\ dry}$ = weight of the oven-dry sub-sample of leaf litter, herb and grass taken to the laboratory to determine moisture content [g]

$W_{subsample,\ wet}$ = weight of the fresh sub-sample of leaf litter, herb and grass taken to the laboratory to determine moisture content [g]

Finally, the carbon content in the LHG was estimated by multiplying with the default carbon fraction 0.47, as recommended by IPCC (2006).

Photo 3: Forest technicians collecting herbs and grasses

Photo 4: Leaf litter collection from nested circular sub-plot of 0.56 m radius

Belowground biomass

Belowground biomass (BGB), commonly known as root biomass, was estimated using a default root-to-shoot ratio value. According to Jan Woodward et al. (2001), measurements of root biomass are highly uncertain and the lack of empirical values for this type of biomass has been a major weakness in ecosystem models for decades. In the current research, the belowground biomass was calculated using a root-to-shoot ratio value of 1:5 (MacDicken 1997); this means that the belowground biomass represents nearly 20% of aboveground tree biomass.

Soil organic carbon

The organic carbon in soil (SOC) can be estimated by taking the average value of four soil samples taken at a depth of 30 cm (IPCC 2006). Thus, three soil samples were taken at 10 cm intervals (0–10 cm, 11–20 cm, and 21–30 cm) with the help of a standardized 300 cm^3 metal soil sampling corer. Stones and plant residue >2 mm (plant residue <2 mm diameter is considered to be soil organic matter) were removed from the soil samples.. One composite soil sample of approximately 100 g was also collected (Photo 4) by mixing the homogeneous soils of all three layers to determine the concentration of organic carbon. Altogether four soil samples (three samples of 300 cm^3 at three depths and one composite sample of 100 g) from each plot were transported to the National Agriculture Research Council lab. At the lab, the soil samples were oven dried at a temperature of 105°C until at a constant weight to determine water content. Finally, two levels of estimation were done to calculate the soil organic carbon. First, soil bulk density was calculated for three samples (0–10 cm, 11–20 cm and 21–30 cm) from each plot then averaged, and then the carbon concentration (%) was derived from the composite soil sample. The soil organic carbon was calculated using the following equation (Pearson et al. 2007, p 30):

$$SOC = \rho \times D \times \% C \quad (4)$$

Where:

SOC = Soil organic carbon stock per unit area [t ha^{-1}]
ρ = Soil bulk density [g cm^{-3}]
D = The total depth at which the sample was taken [cm]
$\% C$ = Carbon concentration [%]

Total forest carbon stock

The carbon values for each forest carbon pool were summed to estimate total forest carbon stock. The following equation was used to calculate the total forest carbon stock:

$$TC\ (LU) = C\ (AGTB) + C\ (AGSB) + C\ (LHG) + C\ (BB) + SOC \quad (5)$$

where,

$TC\ (LU)$ = total carbon stock for a land use category [tC ha^{-1}]
$C\ (AGTB)$ = carbon stock in aboveground tree biomass [tC ha^{-1}]
$C\ (AGSB)$ = carbon stock in aboveground sapling biomass [tC ha^{-1}]
$C\ (LHG)$ = carbon stock in leaf litter, herb and grass [tC ha^{-1}]
$C\ (BB)$ = carbon stock in belowground biomass [tC ha^{-1}]
SOC = soil organic carbon [tC ha^{-1}]

The total forest carbon stock was then converted into tonnes of CO_2 equivalent by multiplying by 3.67, as suggested by Pearson et al. (2007).

Quality assurance and quality control

Adequate quality assessment of an inventory requires both internal and external control procedures. Internal control activities are intended to ensure the accuracy, documentation, and transparency of the inventory operations. An external control is collected through relevant external reviews and is designed to minimize the risk of potential errors and bias. In the current study, provisions for quality assurance (QA) and quality control (QC) were implemented throughout the study period to ensure that the reported carbon stocks and credits are reliable and meet the minimum measurement standards. The QA/QC provisions were applied during the following stages: collecting reliable field measurements; verifying laboratory procedures; and verifying data entry and analysis techniques.

Field measurements

Rigorous standard operating procedures were developed and followed during the fieldwork. The standard operating procedures ensured that the measurements executed by the team at different locations and times were consistent and comparable. All the forest technicians and local resource persons involved in the carbon assessment were fully trained in all aspects of field data collection and data analyses. Field crews were provided with extensive training so as to be fully cognizant of all procedures and to ensure accurate data collection. The forest carbon inventory started in July 2014 and was finalized in the middle of September 2014 to be consistent with the baseline inventory, which was carried out from May to September 2012. Re-measurement of 10% of the plots was completed independently and field data were collected and compared with the original data; all errors were corrected and recorded.

Laboratory measurements

Standard operating procedures for laboratory measurements were also prepared by laboratory staff and were followed for each part of the analysis. About 5% of the dry weight of leaf litter, herbs, and grass and soil samples were reweighed to produce an error estimate, and errors were corrected.

Data entry

Field measurements were recorded on field data sheets and then entered manually into spreadsheets. Data entry was done immediately after the completion of the field measurements. Data entry into spreadsheets is often a significant source of error. Ongoing communication between all personnel involved in measuring and analysing data is critical for resolving apparent anomalies before the final analysis of the monitoring data is completed.

Special attention was paid to the units used in the field, and a standard forestry measurement system was used for the calculation and measurement of all tree DBH, height, and sample weights. All measurements contained in spreadsheets were clearly indicated. Errors were reduced through spot checks of the entered data by forest technicians. In addition, checking each value within an expected range identified any outlier trees.

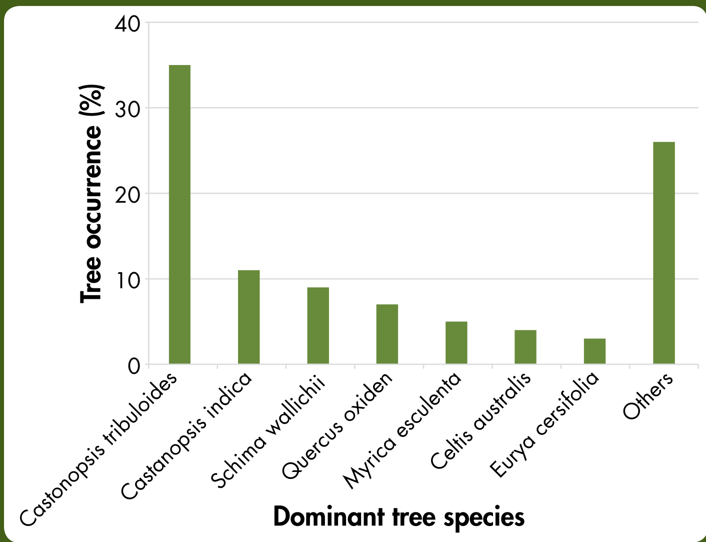
Results and Discussion

General forest parameters

Dominant tree species

Altogether 70 tree species (Annex II) were identified and recorded from the 20 permanent sample plots of the protected forest in the Knowledge Park. The dominant species are *Castonopsis tribuloides* ('masure katus', 35%) and *Castanopsis indica* ('dhale katus', 11%). *Schima wallichii* ('chilaune'), *Quercus oxiden* ('phalat'), *Myrica esculenta* ('kafal'), *Celtis australis* ('ban khari'), and *Eurya cersifolia* ('jhigane') contributed 9%, 7%, 5%, 4%, and 3%, respectively (Figure 5). Another 26% is contributed by other species (*Rhodendron arboreum*, *Brassiopsis hainla*, *Fraxinus floribunda*, etc.) (see Annex II).

Figure 5: **Distribution of dominant tree species at the ICIMOD Knowledge Park**



Tree density

There are a total of 48,390 trees (DBH ≥5 cm) in the protected forest of the Knowledge Park, with an average of 1,613 trees per hectare (Table 1). The total number of trees in each plot is given in Annex III.

Table 1: **Tree density by forest strata at the ICIMOD Knowledge Park**

Strata	No. of plots	No. of trees per hectare
Dense	18	2,527
Sparse	2	700
Total/average	**20**	**1,613**

Source: ICIMOD Knowledge Park forest inventory, 2014

Seedling and sapling density

The average seedling density (height <1 m) and sapling density (height 1.3 m and 5 cm DBH) in the 20 permanent sample plots at the ICIMOD Knowledge Park were 10,505 seedlings per hectare and 1,122 saplings per hectare (Table 2). Thus, the overall status of natural regeneration is good. The plot-wise seedlings and saplings are presented in Annexes IV and V, respectively.

Table 2: **Seedlings and saplings density at the ICIMOD Knowledge Park**

Strata	No. of plots	Seedlings (per hectare)	Saplings (per hectare)
Dense	18	8,271	1,994
Sparse	2	12,738	250
Total/average	**20**	**10,505**	**1,122**
Status of forest		**Excellent**	**Good**

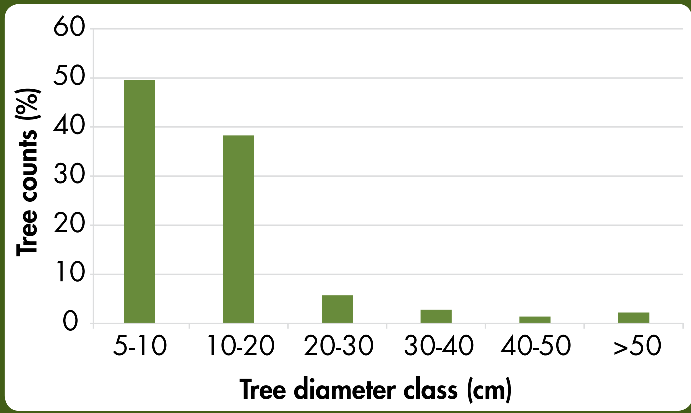
Source: ICIMOD Knowledge Park forest inventory, 2014

Distribution of diameter classes

The proportion of trees of the smaller diameter class was highest, indicating that a very young forest stands in the protected forest of the Knowledge Park. The percentage of trees with DBH class 5–10 cm was 49.6%, DBH class 10–20 cm was 38.3%, DBH class 20–30 cm was 5.7%, DBH class 30–40 cm was 2.8%, DBH class 40–

50 cm was 1.4%, and >50 cm DBH class was 2.2%. Figure 6 describes the percentage of trees scattered over several diameter classes. The DBH distribution showed a right-skewed trend, indicating that most of the trees in all forest strata are young. Sedjo (2001) explained that a young forest can sequester relatively large volumes of additional carbon proportionate to the forest's growth in biomass; however, while an old forest may not sequester additional carbon, it does continue to hold large volumes of carbon. Considering that the forest in the Knowledge Park is young, there is high potential to enhance forest carbon stock. Additionally, maintaining the proportion of old and young trees in a managed forest offers the opportunity to influence forest growth rate allowing more carbon sequestration.

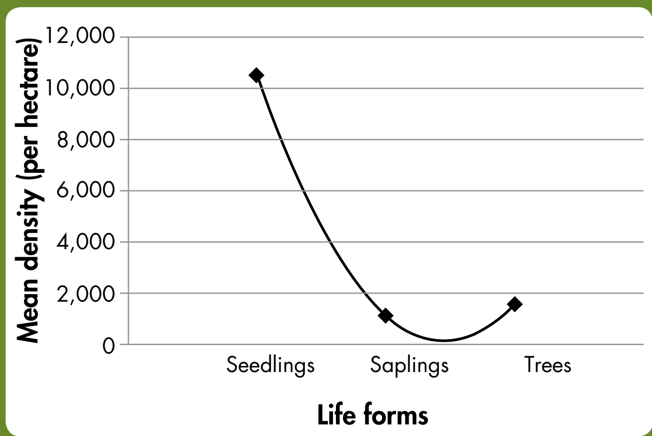
Figure 6: **Diameter class distribution at the ICIMOD Knowledge Park**



Forest structure

The mean density of seedlings per hectare is much higher than that of saplings and trees. The occurrence of a high number of seedlings on the forest floor indicates that the forest is regenerating. This is also evident from the reversed J-shaped distribution (Figure 7), which is an ideal state for the regenerating forests.

Figure 7: **Forest structure at the ICIMOD Knowledge Park**



Basal area

The total basal area of live trees in the protected forest of the Knowledge Park is 827.40 m^2. The average basal area of the trees in the 20 permanent sample plots was calculated at 27.58 m^2 ha^{-1} (Table 3).

Table 3: **Strata-wise basal area at the ICIMOD Knowledge Park**

Stratum	Basal area (m^2 ha^{-1})
Dense	34.65
Sparse	20.52
Average	27.58

Source: ICIMOD Knowledge Park forest inventory, 2014

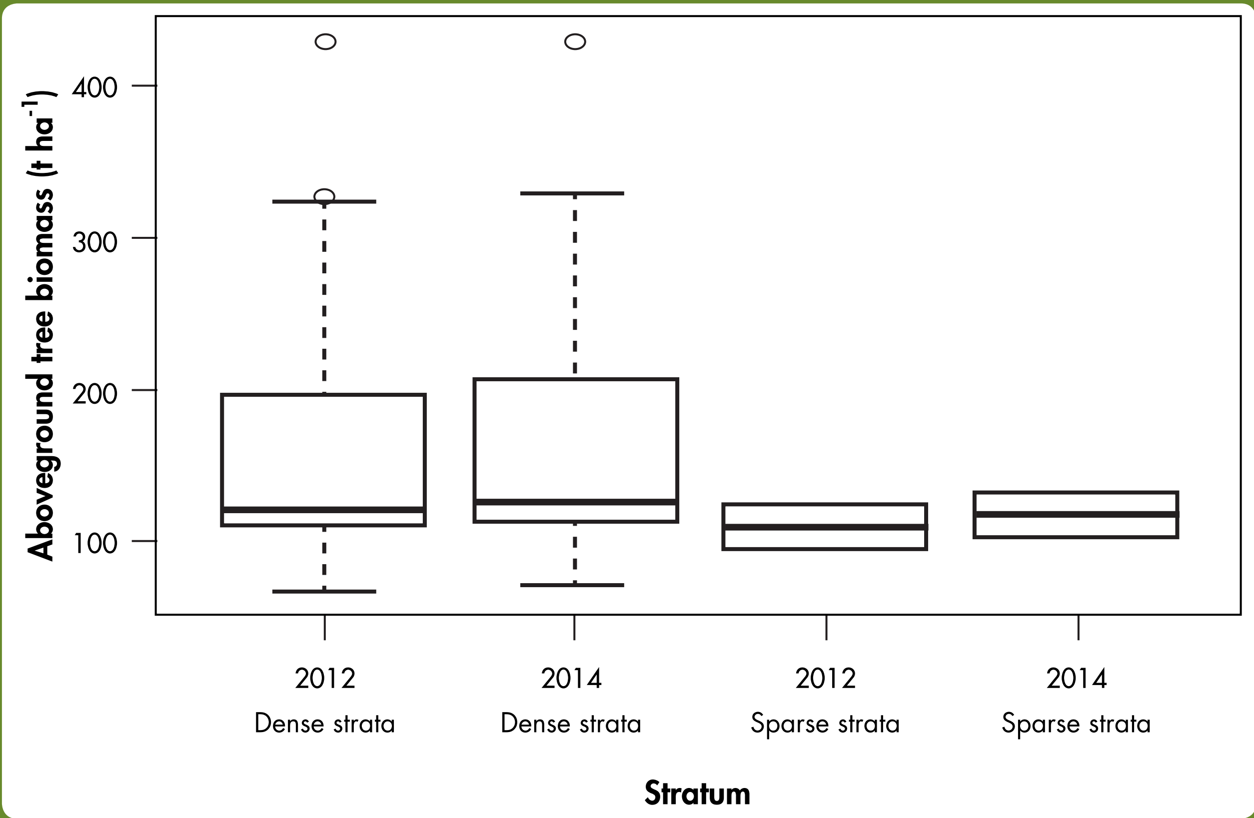
Forest biomass

A total of 1,876 trees were measured in 2012. This number increased to 2,345 in 2014. The total tree number increased because of the progressive development and establishment of new seedlings on the forest floor, which grew and turned into saplings (≤5 cm DBH); 469 of these saplings turned into trees (≥5 cm DBH). About five trees were identified as possible outliers in 2012, whereas only three were identified as outliers in 2014. The mean value of forest biomass in the protected forest of the Knowledge Park was 209.12 t ha^{-1} in 2012 and 220.23 t ha^{-1} in 2014. However, the per hectare value of forest biomass stock (and respective carbon stock) measured in each permanent plot varied significantly (Annex VIII). In the following sections, the pool-wise forest biomass stocks measured in the two monitoring periods are briefly presented.

Aboveground tree biomass

Plots in the dense strata had the most widespread aboveground biomass values compared to plots in the sparse strata during both monitoring periods. The data showed that there were two plots with outlier tree biomass values

Figure 8: **Box-and-whisker plot of tree biomass at the ICIMOD Knowledge Park in 2012 and 2014**



in the dense strata in 2012; the number dropped to one plot in 2014. This shows that there is potential to enhanve tree biomass to an extent. The frequency of outliers seems to be higher in the dense forest strata, as shown in Figure 8.

In the current research, the mean aboveground tree biomass for both dense and sparse strata was estimated to be 177.58 t ha^{-1} and 116.63 t ha^{-1}, respectively. The standard deviation was higher for the dense strata, with a standard error of 14%; however, this is within the acceptable limits. Table 4 gives a detailed summary of statistics for aboveground biomass for all sampled trees in the two forest strata.

Table 4: **Summary of statistics for aboveground tree biomass at the ICIMOD Knowledge Park**

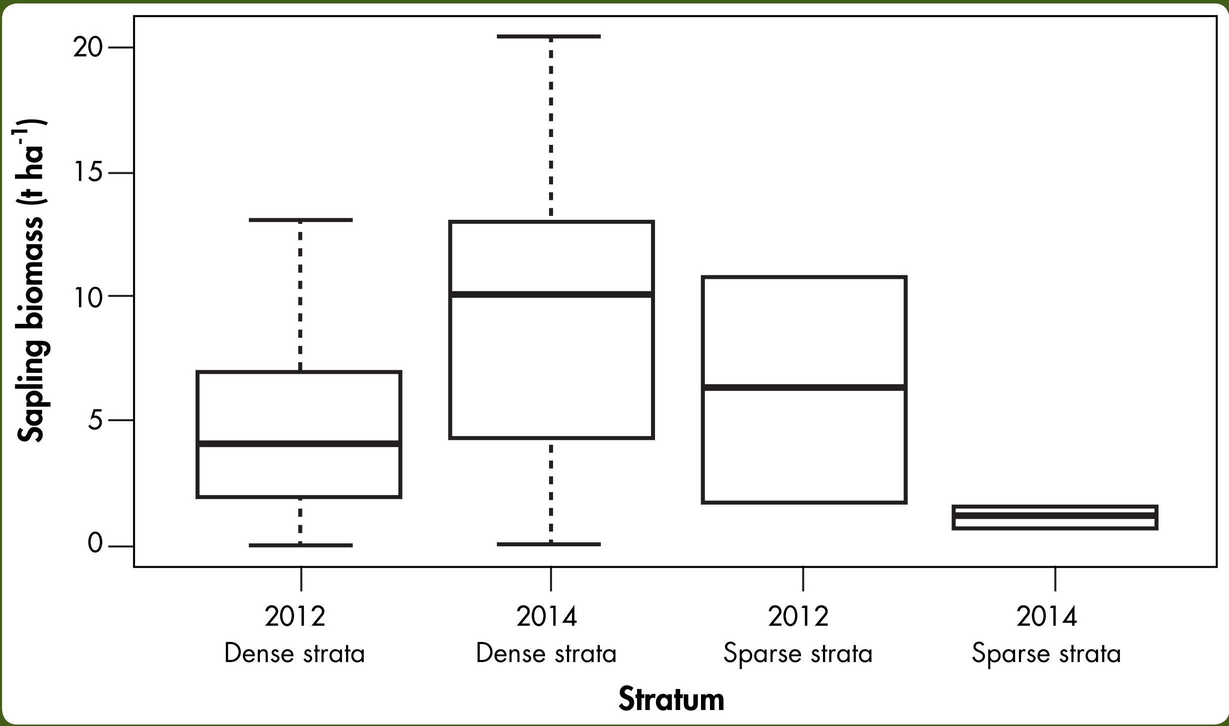
Strata	Mean AGB (t ha^{-1})	Standard deviation AGB	Standard error	95% confidence interval
Dense	177.58	106.88	14	53.15
Sparse	116.63	19.96	12	179.34

Source: ICIMOD Knowledge Park forest inventory, 2014

Aboveground sapling biomass

Figure 9 suggests that in 2014, the dense forest strata had a higher spread of sapling biomass (more than 20 t ha^{-1}), while the sparse forest strata during the same monitoring period, expressed a much lower spread of sapling biomass values (less than 5 t ha^{-1}). The mean sapling biomass for both dense and sparse strata during the monitoring period 2014 was estimated at 9.15 t ha^{-1} and 1.13 t ha^{-1}, respectively. There were no outliers observed in the dense and sparse strata during both the monitoring periods.

Figure 9: **Box-and-whisker plot of sapling biomass at the ICIMOD Knowledge Park in 2012 and 2014**



Herbs and grass biomass

Figure 10 shows that during the 2014 monitoring period the sparse strata had a higher spread of herb and grass biomass (0.59 t ha^{-1}) and that the dense strata had a lower spread (0.31 t ha^{-1}). However, herb and grass biomass in the dense forest strata showed a value of 2.5 t ha^{-1} in some of the sample plots that were marked as outliers. This may be because a better managed forest has a higher probability of enhancing mean herb and grass biomass.

Leaf litter biomass

The mean leaf litter biomass for the 2014 monitoring period was estimated to be 6.10 t ha^{-1} and 2.53 t ha^{-1} respectively in the dense and sparse strata. The higher spread of leaf litter biomass (about 10 t ha^{1}) was expressed by dense forest strata in 2014 and the lower spread (less than 3 t ha^{-1}) was expressed by sparse forest strata in 2014 (Figure 11).

Total forest biomass (above and belowground)

The average total forest biomass in the protected forest of the ICIMOD Knowledge Park was 178.48 t ha^{-1} in 2012, which increased to 186.43 t ha^{-1} in 2014. The above- and belowground biomass of live trees contributed about 78.9% and 15.78% respectively to the total biomass, while saplings, leaf litter, and herb biomass contributed about 2.75%, 2.32%, and 0.25% respectively to the total biomass (Table 5).

Forest soil carbon

The soil organic carbon concentrations (%) and soil carbon (tC ha^{-1}) values were calculated for the 20 permanent plots during the 2012 and 2014 monitoring periods. The results are presented in the following sections.

Figure 10: **Box-and-whisker plot of herbs and grass biomass at the ICIMOD Knowledge Park in 2012 and 2014**

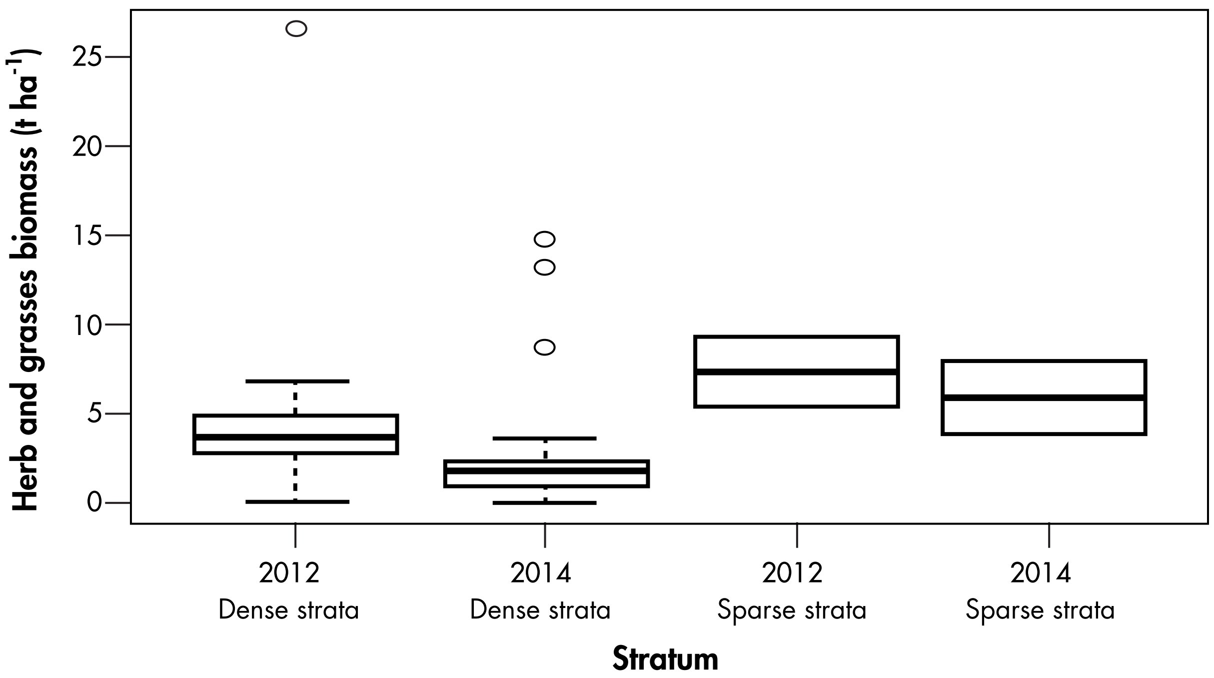


Figure 11: **Box-and-whisker plot of leaf litter biomass at the ICIMOD Knowledge Park in 2012 and 2014**

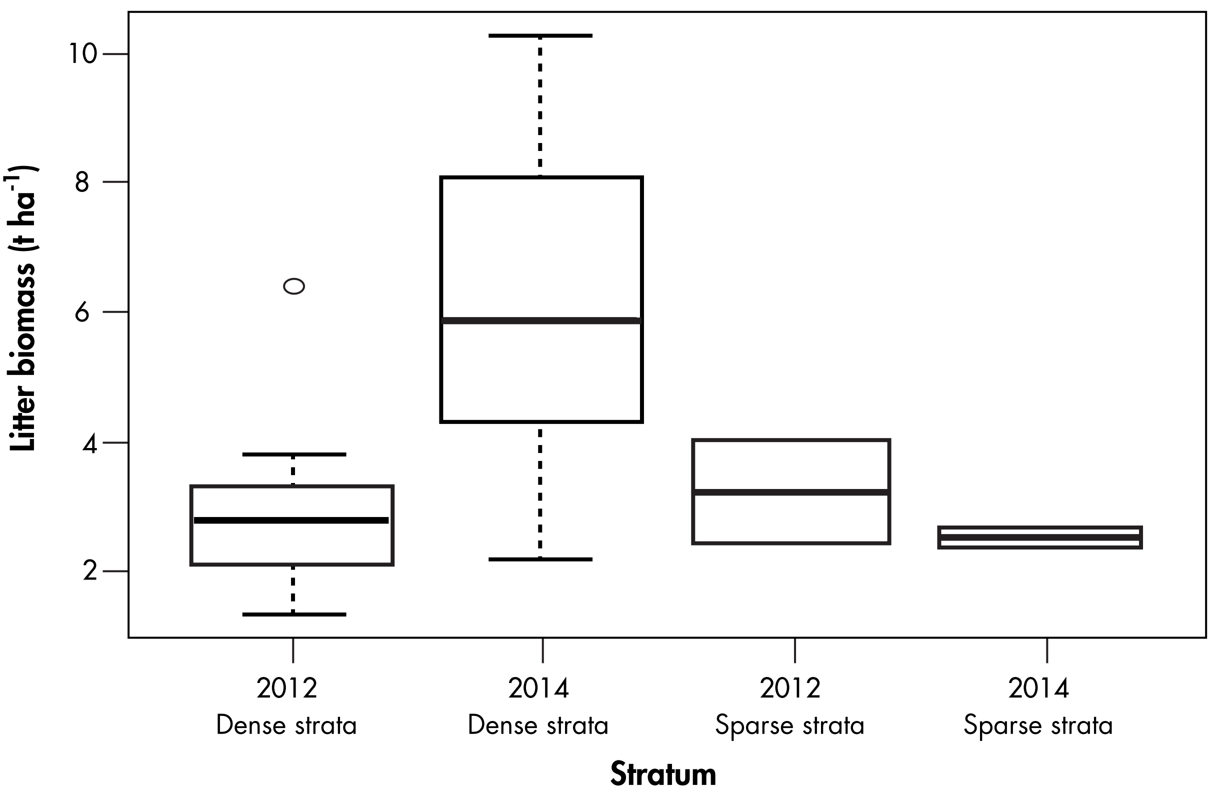


Table 5: **Strata-wise above and belowground biomass at the ICIMOD Knowledge Park in 2014**

	Biomass category	Strata-wise total biomass ($t\ ha^{-1}$)		Average biomass ($t\ ha^{-1}$)	Contribution by percentage (%)
		Dense	Sparse		
Live trees	Aboveground	177.59	116.64	147.11	78.90
	Belowground*	35.52	23.33	29.42	15.78
Sub-total		**213.11**	**139.97**	**176.53**	**94.68**
Saplings	Biomass	9.15	1.13	5.14	2.75
Herbs and grass	Biomass	0.31	0.59	0.45	0.25
Leaf litter	Biomass	6.10	2.53	4.31	2.32
Total		**228.67**	**144.22**	**186.43**	**100.00**

* Calculate using default root to shoot ration (1:5)

Soil bulk density

The bulk density of soil was recorded at three soil depths (0–10 cm, 11–20 cm, and 21–30 cm) collected from all sample plots across the two forest strata. The mean soil bulk density in the 2014 monitoring period was 0.91 g cm^{3-1} and 1.17 g cm^{3-1} for the dense and sparse forest strata, respectively (Table 6).

Table 6: **Distribution of soil organic carbon at the ICIMOD Knowledge Park**

Stratum	Mean bulk density ($g\ cm^{-3}$)	Mean SOC % (fine fraction)	Mean SOC ($tC\ ha^{-1}$)
Dense	0.91	6.01	164.02
Sparse	1.17	5.27	180.93

Source: ICIMOD Knowledge Park forest inventory, 2014

Soil organic carbon percentage

The soil organic carbon percentage of fine fraction was recorded at three soil depths (0–10 cm, 10–20 cm, and 20–30 cm) across the two forest strata. The mean soil organic carbon percentage in the year 2014 was 5.27% and 6.01% for sparse and dense forest strata, respectively (Table 6).

Mean soil organic carbon was significantly higher (180.93 $tC\ ha^{-1}$) in sparse forest strata, than in dense forest strata (164.02 $tC\ ha^{-1}$). The higher values of soil organic carbon in both forest strata indicated that the decomposition rate is relatively slow in the temperate forest due to submissive microbial activities in the wet soil. As a result, soil organic carbon has longer residential time. However, there are many other factors that impact soil organic carbon. Hence, the findings of this study cannot be generalized or extrapolated to other regions of the country and further research is recommended in other similar ecological regions.

The dense broadleaf forest strata, in 2012 and 2014, expressed a higher spread of soil organic carbon values, but the mean soil organic carbon value in the sparse strata, in 2012 and 2014, was higher than in the dense strata. There were no outliers with extreme higher soil organic carbon values in either strata in 2012 and 2014 (Figure 12).

Total forest carbon and carbon sequestration rates

The total forest carbon stock (tC) was calculated by adding together the carbon stock of all individual carbon pools (tree, sapling, litter, herbs and grasses, and soil carbon) in both strata. The following sections present the final results. The different parameters used to calculate total forest carbon stocks are presented in Annex VII.

Total forest carbon stock

The weighted mean carbon stock in the Knowledge Park was 263.44 $tC\ ha^{-1}$ (i.e., 966.68 tCO_2e) in 2012 (Table 7). This increased to 269.22 $tC\ ha^{-1}$ (i.e., 988.04 tCO_2e) in 2014 (Table 8). The aboveground tree components and soil had maximum share of the total forest carbon stock, whereas the herbs contributed the lowest share during both the measurement periods. The pool-wise forest carbon stocks in different forest strata for 2012 and 2014 are shown in Tables 7 and 8 (also see Annex VIII).

Figure 12: **Box-and-whisker plot of soil organic carbon at the ICIMOD Knowledge Park in 2012 and 2014**

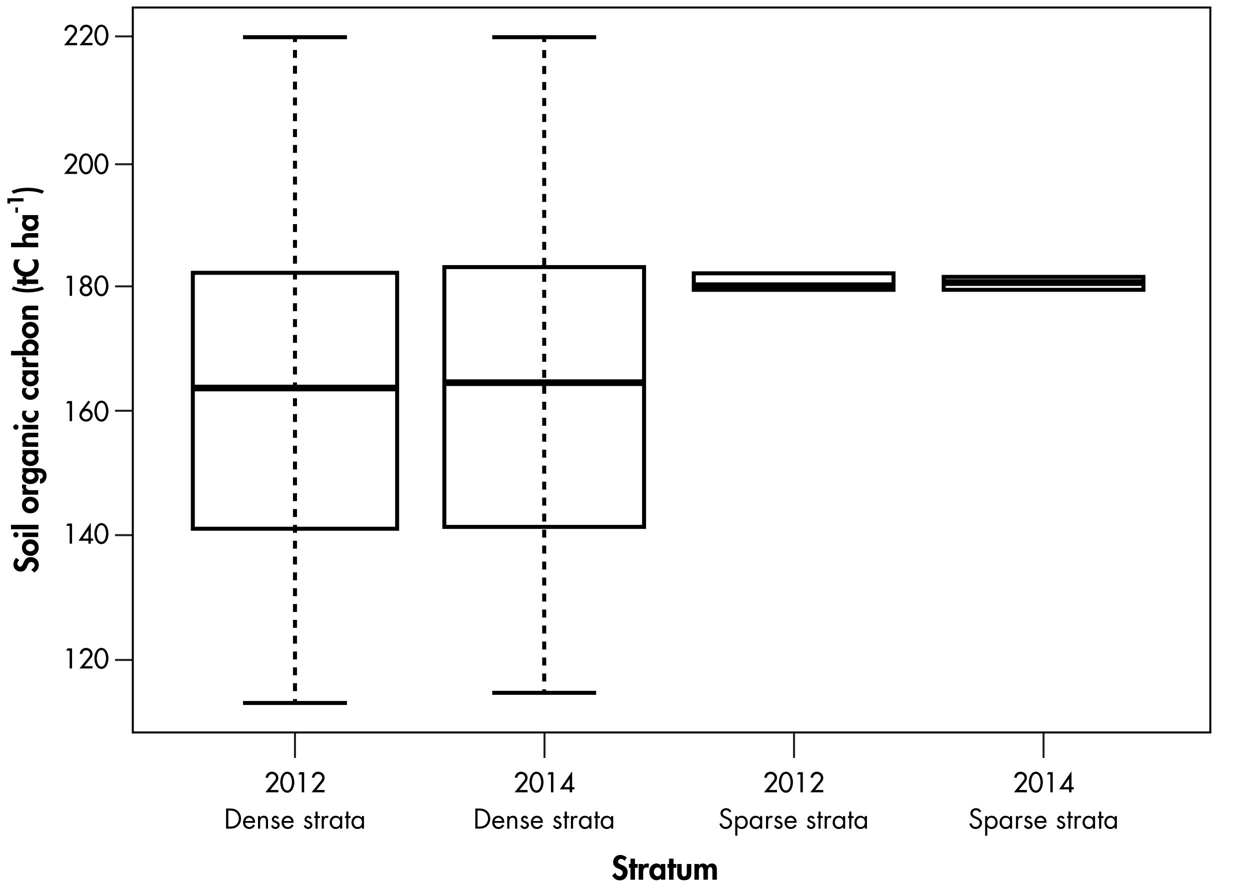


Table 7: **Average weighted value of pool-wise forest carbon stock in different forest strata at the ICIMOD Knowledge Park in 2012**

Strata	Average carbon stocks ($tC\ ha^{-1}$) in different pools						
	Aboveground tree	Belowground tree	Aboveground sapling	Herbs	Litter	Soil	Total carbon in all pools
Dense	81.72	16.34	2.25	0.22	1.36	163.42	265.30
Sparse	50.87	10.17	2.97	0.35	1.52	180.77	246.65
Weighted mean	78.63	15.73	2.32	0.23	1.37	165.151	263.44

Source: ICIMOD Knowledge Park forest inventory, 2012

Table 8: **Average weighted value of pool-wise forest carbon stock in different forest strata at the ICIMOD Knowledge Park in 2014**

Strata	Average carbon stocks ($tC\ ha^{-1}$) in different pools						
	Aboveground tree	Belowground tree	Aboveground saplings	Herbs	Litter	Soil	Total carbon in all pools
Dense	83.47	16.69	4.30	0.15	2.87	164.02	271.50
Sparse	54.82	10.96	0.53	0.28	1.19	180.93	248.72
Weighted mean	80.60	16.12	3.92	0.16	2.70	165.71	269.22

Source: ICIMOD Knowledge Park forest inventory, 2014

The strata-wise changes in the carbon pools, in 2012 and 2014, showed that the sparse strata sequestered higher amounts of aboveground tree carbon (i.e. 3.95 tC ha^{-1}) which might be due to lower species competition which has enhanced tree growth and carbon stock simultaneously. The comparison of average mean carbon stock from 2012 to 2014 showed that there is an increase of 5.78 tC ha^{-1} (Table 9).

Table 9: **Change in carbon pools at the ICIMOD Knowledge Park from 2012–2014**

Strata	Pool-wise carbon stock change from 2012 to 2014 (tC ha^{-1})						
	Aboveground tree	Belowground tree	Aboveground saplings	Herbs	Litter	Soil	Total carbon in all pools
Dense	1.75	0.35	2.05	-0.07	1.51	0.6	6.2
Sparse	3.95	0.79	-2.44	-0.07	-0.33	0.16	2.07
Weighted mean	1.97	0.39	1.6	-0.07	1.33	0.559	5.78

Source: ICIMOD Knowledge Park forest inventory, 2012 and 2014

Forest carbon sequestration rates

The total forest carbon stock at the ICIMOD Knowledge Park is comparable to forest biomass studies done for other central Himalayan forests in the HKH region (Table 10).

At the ICIMOD Knowledge Park, the annual rate of forest carbon sequestration was 2.65 tC $ha^{-1}yr^{1}$ (i.e., 10.68 tCO_2e $ha^{-1}yr^{1}$) (Table 10). This result is comparable and falls within the range of carbon sequestered rates reported for the forests in the central Himalayan region, which is between 2.4 to 5.6 tC $ha^{-1}yr^{1}$ (Rana et al. 1989). The annual forest carbon sequestered at the Knowledge Park was also comparable to the REDD+ pilot sites in the three community forests at different watershed areas in Nepal, i.e., Kayarkhola Watershed in Chitwan, Ludikhola watershed in Gorkha, and Charnawati watershed in Dolakha. The weighted annual carbon sequestration rates in these three sites from 2011 to 2013 were 2.61 tC ha^{-1}, 2.46 tC ha^{-1}, and 3.33 tC ha^{-1}, respectively. Similarly, a study by Malhi et al. (2002) reported a carbon sequestration rate of 2.69 tC ha^{-1} yr^{1} in Indian Himalayan forests. These forests represent tropical and temperate forests ranging from 1,000 to 2,700 masl. The tropical forest consists of mixed species of *Shorea robusta, Acacia catechu*, and *Dalbergia sissoo*, and mostly includes species from the *Dipterocarpaceae* family. *Dipterocarpaceae* species can be either evergreen or deciduous in nature. The

Table 10: **Comparison of carbon stocks in different forest types**

Forest type	Forest carbon stock (tC ha^{-1})	Source
Tropical forest	285.0	Malhi et al. (2000)
Temperate forest	125.0	Malhi et al. (2000)
All central Himalayan forests, India (mean)	250–300	Singh and Singh (1992)
Seven central Himalayan forests, India (mean)	166.8–440.10	Rana et al. (1989)
Kayarkhola, Ludikhola, and Charnawati watersheds, Nepal	226.30–234.70	REDD+ pilot project report (implemented by ANSAB, ICIMOD and FECOFUN, from 2009–2013) (Measurements taken in 2010, 2011, 2012 and 2013; 226.30 $tCha^{-1}$ represents baseline year carbon stock and 234.70 represents incremental carbon in the year 2013)
Terai forests, Nepal	124.14	FRA (2014a)
Churia forests, Nepal	116.94	FRA (2014b)
Mid-hill forests, Nepal	157.80	FRA (2014c
Terai Arc Landscape (TAL), Nepal	237.74	WWF Nepal (2011)
Chitwan Annapurna Landscape (CHAL), Nepal	197.80	Subedi et al. (2015)
ICIMOD Knowledge Park forest, Godavari, Nepal	269.22	Carbon stock assessment at the ICIMOD Knowledge Park, 2014

temperate zones support broadleaf deciduous forests and evergreen coniferous forests where species such as *Quercus leucotricophora, Quercus lanata*, *Quercus floribunda* and, *Quercus lamellosa* grow abundantly. The lower temperate zone supports mixed broadleaf forest, with abundant *Lauraceae*, and *Pinus wallichiiana* trees.

Forest disturbances and risks

Disturbance incidences and potential risks

Out of 20 permanent sample plots measured in the protected forest of the Knowledge Park, 18 are naturally regenerated forest and two are partial plantations. Referring to the literature, there are six main disturbance indicators for forests: forest fire, fodder collection, lopping, grazing, timber extraction, and landslide and soil erosion. The Knowledge Park showed no signs of forest fire, grazing, or soil erosion. However, two sparse and 15 dense plots in the study showed disturbance caused by fodder collection. There are seven plots that showed signs of lopping, and one plot (Plot 18) showed a fresh cut tree stump for timber collection (Annex IX). These records show insignificant disturbance which has not affected forest growth and carbon sequestration and emissions (Table 11).

The study conducted as part of ICIMOD's REDD+ pilot project (2009–2013) recorded six major forest disturbance indicators from 593 permanent plots distributed in three watersheds of Nepal. Among these permanent plots, 6% of plots showed signs of forest fire, 57% loping, 27% grazing, 26% fuelwood collection, 8% timber extraction, and 6% were identified as showing signs of soil erosion. Similarly, another study conducted in the year 2014 by ANSAB, ICIMOD, UNIQUE, and WWF Nepal in the Chitwan Annapurna Landscape (CHAL) of Nepal identified fuelwood collection, grazing, and lopping as the major threats causing forest degradation. About 66.7%, 53.3%, 47.7%, and 38.3% of forest plots showed effects of fuelwood collection, uncontrolled grazing, lopping, and timber extraction, respectively. These comparisons with other forests types within Nepal indicated that protected forests at the Knowledge Park show no obvious signs of forest disturbance.

Table 11: **Carbon sequestration rates from different carbon pools at the ICIMOD Knowledge Park in 2012 and 2014**

Carbon pool	Mean carbon in 2012 (C1, tC ha^{-1})	Mean carbon in 2014 (C2, tC ha^{-1})	Net change in carbon ($\Delta C = C_2 - C_1$)	Carbon sequestration rate $\Delta C = C_2 - C_1/2$ (tC ha^{-1} yr^{-1})
AGTB	78.63	80.60	1.97	0.98
BGTB	15.73	16.12	0.39	0.20
Saplings	2.32	3.92	1.60	0.80
Herbs and grasses	1.37	2.70	1.33	0.67
Total	98.05	103.34	5.29	2.65

Source: ICIMOD Knowledge Park forest inventory, 2012 and 2014

Conclusion and Future Research

Conclusion

This study provides current estimation of forest biomass, carbon stock, and annual carbon sequestration in the protected forest of the ICIMOD Knowledge Park at Godavari, which are important biophysical outcomes of the forest landscape. Being an entry point initiative, the results of and findings from this inventory need to be cross-checked and validated by other research in comparable ecological zones. At the same time, tree density in the protected forest of the ICIMOD Knowledge Park is not consistent with basal area, which means that the forest is not of an even age in all plots and indicates that silviculture treatments are not being uniformly applied.

A total of 20 permanent sample plots with two sparse and 18 dense strata in plantation and natural forests were assessed in the year 2014. Vegetation parameters, along with the total carbon stock and annual carbon sequestration were calculated separately for different forest carbon pools. It can be concluded that the forest, on both strata, can sequester more carbon in the future as the trees have still low DBH values, which means a greater tendency to build biomass, and therefore carbon content. Seven species types, namely, *Castonopsis tribuloides* ('masure katus'), *Castanopsis indica* ('dhale katus'), *Schima wallichii* ('chilaune'), *Quercus oxiden* ('phalat'), *Myrica esculenta* ('kafal'), *Celtis australis* ('ban khari'), and *Eurya cersifolia* ('jhigane') were the dominant tree species in both strata on the basis of density and basal area.

Regarding tree species diversity, altogether 70 tree species (15 tree species in sparse and 55 tree species in dense forest strata) were recorded in the Knowledge Park. In the dense strata, the mean tree density was 2,527 trees per hectare and the mean basal area was 34.65 m^2 ha^{-1}, whereas the sparse strata had a tree density of 700 trees per hectare with the basal area of 20.12 m^2 ha^{-1}.

The carbon stock density of dense forest strata (271.50 tC ha^{-1}) was higher than that of the sparse strata (248.72 tC ha^{-1}). All the values for measured carbon pools, except soil organic carbon were higher in the dense strata. The soil organic carbon was 164.02 tC ha^{-1} in dense forest strata and 180.93 tC ha^{-1} in sparse strata. The annual carbon sequestration in the protected forest of the ICIMOD Knowledge Park was 2.65 tC ha^{-1}.

Future research

The research site offers ideal opportunities to estimate ecosystem services, including water quantity and quality, biodiversity, and aesthetic and recreational services, which are important aspects of the forest ecosystems. Quantifying such ecosystem services will provide information to explore relationships (trade-offs and synergies) among different ecosystem services (forest carbon, biodiversity, water benefits, etc.). Hands-on information about forest ecosystem services offers valuable ideas to managers and decision-makers in devising proper forest management strategies that generate all services in synergy. The research team thus strongly recommends developing a framework for assessing ecosystem services trade-offs and synergies in the future, and adopting a good management regime.

As long as seminal work is being done in the protected forest of the ICIMOD Knowledge Park, we recommend undertaking a periodic inventory and monitoring of forest carbon stocks. The permanent research site at the Knowledge Park provides a unique opportunity for long-term forest carbon assessments. In addition, the local resource persons at the Knowledge Park were fully trained during the 2014 forest inventory and could be mobilized as local resource persons to independently conduct forest carbon inventories in the field. The expert knowledge of local resource persons can be valuable to visitors, students, and local communities who want to learn by visiting ICIMOD's project sites. Finally, research findings and success stories from the area should to disseminated to a wider audience (such as students, visitors, and the academia) through printed brochures, leaflets, online portals, and on-site demonstrations.

References

Acharya, KP; Dangi, R (2011) 'Understanding forest degradation in Nepal.' *Unasylva* 238: 62

Allen, JC; Barnes, DF (1985) 'The causes of deforestation in developing countries.' *Annals of the association of American Geographers 75*(2): 163–184

Amatya, SM; Shrestha, KR (2010) *Nepal forestry handbook*. Kathmandu, Nepal: Forestry Research Support Programme for Asia and the Pacific

Branney, P; Yadav, KP (1988) *Changes in community forests conditions and management 1994–1998: Analysis of information from the forest resources assessment study and socio-economic study in Koshi Hills*. Project Report G/ NUKCFP/32. Kathmandu, Nepal: Nepal UK Community Forestry Project

Carter, J; Pokharel, B; Rai, R; Paraiuli, D (2011) *Two decades of community forestry in Nepal: What have we learned?* Kathmandu, Nepal: Nepal Swiss Community Forestry Project

Central Bureau of Statistics (2011) *Environmental statistics of Nepal*. Kathmandu, Nepal: National Planning Commission, Government of Nepal

Chave, J; Andalo, C; Brown, S; Cairns, MA; Chambers, JQ; Eamus, D; Fölster, H; Fromard, F; Higuchi, N; Kira, T; Lescure, JP; Nelson, BW; Ogawa, H; Puig, H; Riéra, B; Yamakura, T (2005). 'Tree allometry and improved estimation of carbon stocks and balance in tropical forests.' *Oecologia* 145(1): 87–99

Department of Forest Research and Survey (1999) *Forest resources of Nepal*, Department of Forest Research and Survey Report No. 74. Kathmandu, Nepal: Department of Forest Research and Survey, Ministry of Forest and Soil Conservation, His Majesty's Government of Nepal/ FINIDA

Escobedo, FJ; Kroeger, T; Wagner, JE (2011) 'Urban forests and pollution mitigation: Analyzing ecosystem services and disservices'. *Environmental Pollution* 159: 2078–2087

FAO (2005a) *Global forest resources assessment 2005: Nepal country report*. Forestry Department, Food and Agriculture Organisation, Country Report 192. Rome, Italy: Food and Agriculture Organization (FAO)

FAO (2015b) *FAO assessment of forests and carbon stocks, 1990–2015 Reduced overall emissions, but increased degradation*. Rome, Italy: Food and Agriculture Organization

Forest Agency (2011) *Manual for baseline survey of forest ecosystem diversity*. Tokyo, Japan: Forest Agency of Japan

FRA (2010) *Field manual. Nepal, forest resource assessment*. Kathmandu, Nepal: Department of Forest Research and Survey, Ministry of Forests and Soil Conservation, Nepal

FRA (2014a) *Terai forests of Nepal, forest resource assessment*. Kathmandu, Nepal: Department of Forest Research and Survey, Ministry of Forests and Soil Conservation, Nepal

FRA (2014b) *Siwalik forests of Nepal, forest resource assessment*. Kathmandu, Nepal: Department of Forest Research and Survey, Ministry of Forests and Soil Conservation, Nepal

Gautam, AP; Webb, EL; Shivakoti, GP; Zoebisch MA (2003) 'Land use dynamics and landscape change pattern in a mountain watershed in Nepal.' *Agriculture Ecosystems and Environment* 99: 83–96

Geider, RJ; Delucia, EH; Falkowski, PG; Finzi, AC; Grime, JP; Grace, J; Kana, TM; La Roche, J; Long, SP; Osborne, BA (2001). 'Primary productivity of planet earth: biological determinants and physical constraints in terrestrial and aquatic habitats.' *Global Change Biology 7*(8): 849–882

ICIMOD (2011) *REDD+ pilot project annual report*. Unpublished report submitted to ICIMOD, Kathmandu, Nepal

ICIMOD (2012) *Godavari forest carbon status*. Kathmandu, Nepal: ICIMOD

ICIMOD; ANSAB; FECOFUN (2010) *Forest carbon measurement guidelines*. Kathmandu, Nepal: ICIMOD

IPCC (2001) *Climate Change 2001: The scientific basis*. Working Group I. New York, USA: Cambridge University Press

IPCC (2006) *Good practice guidelines for national greenhouse gas inventories*. Switzerland: Intergovernmental Panel on Climate Change

Joshi, GR; Bhatta, N (2010) Early Action Forest Carbon Project to prepare for REDD+ and have an equitable carbon financing mechanism in place: Climate, community and biodiversity benefits. Kathmandu, Nepal: WWF Nepal

Kant S; Bi, YM; Rothstein, SJ (2011) 'Understanding plant response to nitrogen limitation for the improvement of crop nitrogen use efficiency'. *Journal of Experimental Botany* 62: 1499–1509

Ma, J; Hu, Y; Bu, R; Chang, Y; Deng, H; Qin, Q (2014) 'Predicting impacts of climate change on the aboveground carbon sequestration rate of a temperate forest in Northeastern China'. *PLoS one*, 9(4), e96157.

MacDicken, KG (1997) *A guide to monitoring carbon storage in forestry and agro-forestry projects*. Arlington, USA: Winrock International

Malhi, Y; Phillips, OL; Martinez, RV; Arroyo, L; Baker, T; Killeen, T; Lewis, SL; Mendoza, AM; Neill, D; Nunez Vargas, P; Alexiades, M; Ceron, C; di Fiore, A; Erwin, T; Jardim, A; Palacios, W; Saldias, M; Vinceti, B (2002) 'Increasing dominance of large lianas in Amazonian forests.' *Nature* 418: 770–774

Millar, CI; Stephenson, LN; Stephens, SL (2007) 'Climate change and forests of the future: managing in the face of uncertainty'. *Ecological applications*, 17(8), 2145-2151

Miura, S (2000) 'Proposal for a new definition to evaluate the status of forest floor cover and floor cover percentage (FCP) from the viewpoint of the protection against raindrop splash.' *Journal of Japanese Forest Society* 82: 132–140

Miura, S; Hirai, K; Yamada, T (2002) 'Transport rates of surface materials on steep forested slopes induced by raindrop splash erosion.' *Journal of Forest Research* 7: 201–211

Miura, S; Yoshinaga, S; Yamada, T (2003) 'Protective effect of floor cover against soil erosion on steep slopes forested with Chamaecyparis obtusa (hinoki) and other species.' *Journal of Forest Research* 8: 27–35

MOFSC (1988) *Master plan for the forestry sector Nepal*. Appendix Table 2.2: Forest types, representative species, uses and wood density. Kathmandu, Nepal: Ministry of Forests and Soil Conservation, His Majestry Government of Nepal

MOFSC (2002) *Nepal biodiversity strategy*. Kathmandu, Nepal: Ministry of Forests and Soil Conservation, His Majesty's Government of Nepal

Pan, Y; Birdsey, RA; Fang, J; Houghton, R; Kauppi, PE; Kurz, WA; Ciais, P (2011) 'A large and persistent carbon sink in the world's forests'. *Science*, 333(6045), 988-993

Paoletti, E (2009) 'Ozone and urban forests in Italy'. *Environmental Pollution* 157: 1506–1512

Pearson, TR; Brown, SL; Birdsey, RA (2007) *Measurement guidelines for the sequestration of forest carbon*. US: Northern Research Station, Department of Agriculture. http://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs18.pdf (accessed 27 May 2010)

Pearson, T; Walker, S; Brown, S (2005) *Sourcebook for land-use, land-use change and forestry projects*. Winrock International; the Bio Carbon Fund of the World Bank

R Development Core Team (2009) *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. http://www.R-project.org (accessed 25 June 2010)

Raich, JW; Clark, DA; Schwendenmann, L; Wood, TE (2014) 'Aboveground tree growth varies with belowground carbon allocation in a tropical rainforest environment'. *PloS one*, 9(6), e100275

Rana, BS; Singh, RP; Singh, SP (1989) 'Carbon and energy dynamics of seven central Himalayan forests.' *Tropical Ecology* 30(2): 253–264

Ravindranath, NH; Ostwald, M (2007) *Carbon inventory methods: Handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects*. Springer Science & Business Media

Scott, NA; Rodrigues, CA; Hughes, H, Lee, JT; Davidson, EA; Dail, DB; Hollinger, DY (2004) 'Changes in carbon storage and net carbon exchange one year after an initial shelterwood harvest at Howland Forest, ME'. *Environmental Management*, 33(1), S9-S22

Sedjo, RA (2001) *Forest carbon sequestration: Some issues for forest investments*. Washington, DC: Resources for the Future

Singh, JS; Singh, SP (1987) 'Forest vegetation of the Himalaya.' *Botanical Review* 52: 80–192

Singh, JS; Singh, SP (1992) *Forest of Himalaya: Structure, functioning and impact of man*. Nainital, India: Gyanodaya Prakashan

Stern, NH (2007) *The economics of climate change: The Stern review (pre-publication edition)*. Cambridge: Cambridge University Press

Subedi, BP; Pandey, SS; Pandey, A; Rana, EB; Bhattarai, S; Banskota, TR; Charmakar, S; Tamrakar, R (2010) *Guidelines for measuring carbon stocks in community-managed forests*. ANSAB, FECOFUN, ICIMOD, NORAD. http://www.ansab.org/wp-content/uploads/2010/08/Carbon-Measurement-Guideline-REDD-final.pdf (accessed 25 June 2011)

Subedi, BP; Gauli, K; Joshi, NR; Pandey, A; Charmakar, S; Poudel, A; Murthy, MRS; Glani, H; Khanal, SC (2015) *Forest Carbon Assessment in Chitwan-Annapurna Landscape for REDD+ Readiness Activities*. Study Report. Kathmandu, Nepal: WWF Nepal Hariyo Ban Program

Tamrakar, P (2000) *Biomass and volume table with species description for community managed forest*. Kathmandu, Nepal: Department of Forest, Nepal

UNFCCC (2009) Calculation of the number of sample plots for measurements with A/R

Zhao M; Kong, Z; Escobedo, FG, Gao, J (2010) 'Impacts of urban forests on offsetting carbon emissions from industrial energy use in Hangzhou, China'. *Journal of Environmental Management* 91: 807–813

Annex I: **GPS coordinates of permanent plots at the ICIMOD Knowledge Park**

Plot number	Strata	Latitude (GPS X)	Longitude (GPS Y)	GPS altitude (m)	Aspect	Forest type
1	Dense	340832	3053158	1,576	Flat	Natural
2	Sparse	341258	3053128	1,590	NW	Plantation
3	Dense	340858	3053168	1,577	Flat	Natural
4	Dense	341382	3052800	1,712	NW	Natural
5	Dense	340775	3053075	1,585	NW	Plantation
6	Dense	341097	3053053	1,589	NW	Natural
7	Dense	341278	3052997	1,651	NW	Natural
10	Dense	340803	3052983	1,492	NE	Natural
11	Dense	341129	3052950	1,632	NW	Natural
12	Dense	340997	3052946	1,493	NE	Natural
14	Dense	341166	3052824	1,694	NE	Natural
15	Dense	341312	3052875	1,659	NE	Natural
18	Dense	340833	3052928	1,690	NE	Natural
19	Dense	341214	3052897	1,651	NE	Natural
20	Dense	341134	3052723	1,773	NE	Natural
22	Dense	340694	3053116	1,570	NW	Natural
23	Dense	341040	3053132	1,566	N	Natural
26	Dense	341282	3052771	1,758	NE	Natural
27	Sparse	340982	3053046	1,586	NW	Natural
29	Dense	341026	3052734	1,771	NE	Natural

Annex II: **Wood-specific gravity value for different tree species**

SN	Local name	Scientific name	Wood-specific density
1	Aarubakhada	*Prunus domistica* L.	0.594
2	Angeri	*Lyonia villosa* (Hook. f.) Hand.- Mazz.	0.594
3	Arkhaulo	*Lithocarpus pachyphylla* (Kurz) Rehder	0.930
4	Aru	*Prunus persica* (L.) Seib. and Zucc.	0.594
5	Bakle pat (kalo)	*Cleyera ochnacea* DC.	0.594
6	Baklepat (seto)	*Cleyera japonica* Thunb. var.	0.594
7	Banjh	*Quercus incina* W. Bartram	0.594
8	Bamboo	*Dendrocalamus calostachys*	0.594
9	Ban chanp (seto)	*Michelia excelsa* (Wall.) Blume	0.560
10	Ban khari	*Celtis australis* L.	0.720
11	Bhakiamilo	*Rhus javanica* L.	0.594
12	Bhalayo	*Rhus wallichii* Hook. f.	0.594
13	Bhimsenpati	*Rabdosia ternifolia* (D. Don) Hara.	0.594
14	Chanp	*Michelia champaka* L.	0.560
15	Chilaune	*Schima wallichii* (DC.) Korth.	0.690
16	Chinnea	*Acanthopanax cissifolius*	0.594
17	Chiplekaulo (seto)	*Persea odoratissima* (Nees) Kosterm.	0.594
18	Dhare kanda	*Xylosma longifolium* Clos	0.594
19	Dhaire	*Woodfordia fruticosa* (L.) Kurz.	0.594
20	Dhalne katus	*Castanopsis indica* (Roxb.) Miq.	0.700
21	Dudhilo	*Ficus neriifolia* Sm.	0.594
22	Ghigane	*Euria cerasifolia* (D.Don) Kobuski	0.600
23	Gobre salla	*Pinus wallichiana* A.B. Jackson	0.480
24	Guphal	*Holbolea latifolia*	0.594
25	Guras	*Rhodendron arboreum* L.	0.640
26	Hadebayar	*Zizyphus recurva* Lam.	0.930
27	Bayar	*Zizyphus mauritiana* Lam.	0.930
28	Hattipaile	*Brassiopsis hainla*	0.594
29	Ipilipil	*Leucaena leucocephala* (Lam.) De Wit	0.540
30	Jure mayal	*Stranvaesis nussia* Decene	0.700
31	Jamanemandro	*Mahonia nepalensis*	0.700
32	Kafal	*Myrica esculenta* Bch.-Ham.ex d.Don	0.750
33	Kainyo	*Grevillia robusta* A.Cunn.ex R.Br.	0.570
34	Kholme	*Symplocos racemosa* Roxb. var.	0.594
35	Kalikath	*Miliusa velutina* (Dunal) Hook. F.& Thoms	0.594
36	Kashru	*Quercus semicarpifolia* Sm.	0.594
37	Kanike	*Ligustrum indicum*	0.594
38	Kapur	*Cinnamomum camphora*	0.600
39	Kathe kaulo	*Persea gamblei* (King ex Hook. f.)	0.594
40	Kaulo	*Persea duthiei* (king ex Hook.f.)	0.594
41	Khote salla	*Pinus roxburghii* Sarg.	0.650
42	Kimbu	*Morus australis* Poir.	0.750
43	Koiralo	*Bauhnia purpurea* L.	0.700
44	Kukath	*Rhamnus*	0.594
45	Lapsi	*Choerospondias axillaris Roxb.)* B.L.	0.640
46	Lampate	*Duabanga grandiflora* (Roxb. ex DC.)	0.500

SN	Local name	Scientific name	Wood specific density
47	Lakuri	*Fraxinus floribunda* Wall.	0.770
48	Latimauwa	*Madhuca latifolia* (Roxb.) Macbride	0.400
49	Mail	*Macaranga denticulata* (Blume) Mull-Arg	0.700
50	Mauwa	*Engelhardia spicata Leschen.* ex Blume	0.594
51	Madilo	*Elaegnus conferata*	0.594
52	Mayal	*Pyrus pashia Buch.*- Ham. ex D.Don	0.594
53	Millitia japonica	*Millitia Japonica*	0.594
54	Mirmire	*Indigofera pulchella* Roxb.	0.594
55	Musure katus	*Castanopsis tribuloides* (Sm.) A. DC.	0.600
56	Naspati	*Pyrus communis* L.	0.594
57	Niwaro	*Ficus auriculata* Lour.	0.594
58	Pahele chanp	*Michelia kisopa*	0.560
59	Paheli kath	*Litsea lancifolia* (Roxb. ex Nees) Hook. f.	0.594
60	Paiyou	*Prunus cerasoides*	0.720
61	Phalat	*Quercus lanata* Sm.	0.940
62	Phirphire	*Acer oblongum* Wall. ex DC.	0.720
63	Phusre	*Grewia subinaqalis* DC.	0.594
64	Puwale	*Ilex dioniana* DC.	0.594
65	Rani salla	*Pinus roxburghii* Sarg.	0.480
66	Setikath	*Hymenodictyon excelsum* (Roxb.) Wall.	0.594
67	Seto chanp	*Michelia champaca* L.	0.560
68	Siris	*Albizia lebbeck* (L.) Benth.	0.700
69	Tejpat	*Cinnamomum tamala* (Buch.-Ham.)	0.594
70	Utis	*Alnus nepalensis* D. Don.	0.440

Annex III: **Number of trees in plots at the ICIMOD Knowledge Park in 2014 and their DBH range**

	Plot No.	Number of trees in a plot (500 m^2)	Total no of trees (ha)	Strata-wise average trees per hectare	Tree DBH (range: max-min) in cm
Dense	1	113	2,260	2,527.77778	5–25.8
	3	100	2,000		5–34.1
	4	75	1,500		5–58.5
	5	173	3,460		5–25.0
	6	141	2,820		5–32.6
	7	188	3,760		5–22.1
	10	229	4,580		5–24.6
	11	95	1,900		5–44.0
	12	87	1,740		5–27.5
	14	79	1,580		5–33.6
	15	110	2,200		5–47.0
	18	105	2,100		5–53.1
	19	206	4,120		5–30.1
	20	75	1,500		5–44.0
	22	141	2,820		5–23.2
	23	101	2,020		5–33.0
	26	125	2,500		5–43.5
	29	132	2,640		5–61.0
Sparse	2	37	740	700	5–30.8
	27	33	660		5–45.1

Annex IV: **Plot-wise seedling/regeneration status in carbon monitoring plots at the ICIMOD Knowledge Park in 2014**

Strata	Plot	Seedlings/regeneration (per hectare)	Strata wise average
Dense	1	6,369.43	8,271.41
	3	11,146.50	
	4	3,184.71	
	5	11,146.50	
	6	7,431.00	
	7	12,738.85	
	10	3,184.71	
	11	3,184.71	
	12	3,980.89	
	14	7,961.78	
	15	3,184.71	
	18	7,961.78	
	19	12,738.85	
	20	9,554.14	
	22	9,554.14	
	23	17,515.92	
	26	12,738.85	
	29	5,307.86	
	2	15,923.57	12,738.85
	27	9,554.14	

Annex V: **Plot-wise sapling status in carbon monitoring plots at the ICIMOD Knowledge Park in 2014**

Strata	Plot	Sapling density (per hectare)	Strata wise average
Dense	1	1,300	1,944
	3	400	
	4	2,600	
	5	3,900	
	6	600	
	7	4,200	
	10	3,600	
	11	800	
	12	2,300	
	14	700	
	15	2,800	
	18	2,700	
	19	1,900	
	20	2,500	
	22	3,000	
	23	200	
	26	100	
	29	2,300	
Sparse	2	100	250
	27	400	

Annex VI: **Plot-wise aboveground tree biomass and tree density and basal area at the ICIMOD Knowledge Park in 2014**

Strata	Plot	AGTB (t ha^{-1})	Tree density (per hectare)	Tree basal area (m^2 ha^{-1})
Dense	1	86.40	2,260	17.66
Dense	3	103.25	2,000	22.01
Dense	4	328.40	1,500	42.77
Dense	5	112.40	3,440	26.74
Dense	6	115.25	2,820	32.11
Dense	7	90.20	3,760	26.20
Dense	10	112.60	4,580	36.17
Dense	11	194.58	1,900	36.07
Dense	12	113.05	1,740	22.14
Dense	14	118.50	1,580	25.22
Dense	15	186.33	2,200	31.82
Dense	18	327.58	2,100	58.08
Dense	19	131.70	4,120	35.01
Dense	20	205.20	1,500	37.17
Dense	22	70.32	2,820	18.77
Dense	23	180.20	2,020	31.19
Dense	26	246.32	2,500	41.03
Dense	29	474.28	2,640	83.63
Sparse	2	102.52	740	18.29
Sparse	27	130.75	660	22.75

Annex VII: **Parameters of biomass equation (a and b) used for different species of saplings**

Scientific name	Local name	Intercept (a)	Slope (b)	R squared
Alnus neplensis	Utis	-2.348	2.102	0.978
Casearia graveolens	Barkamle	-1.627	1.520	0.990
Castanopsis indica	Katus	-0.710	1.720	0.970
Engelhardia spicata	Mauwa	-2.142	1.938	0.987
Eurya acuminata	Jhigune	-1.743	1.797	0.981
Ficus neriifolia	Dudilo	-0.986	1.750	-
Ficus semicordata	Khanyo	-1.370	2.010	0.940
Fraxinus floribunda	Lakuri	-2.130	2.082	0.971
Litsea monopetala	kutmero	-1.880	2.260	0.940
Lyonia ovalifolia	Angari	-2.833	2.010	0.990
Maesa macrophylla	bhokate	-1.769	1.650	0.766
Melastoma melabathricum	Chulese	3.670	1.050	0.980
Myrica esculenta	Kafal	-2.535	1.403	0.848
Myrsine capitellata	Setokath	-1.859	1.932	0.979
Phyllanthus embilica	Amala	-2.046	1.889	0.968
Pinus roxburghii	Sallo	-3.985	2.744	0.990
Pinus wallichiana	Ghoge sallo	-1.816	1.816	0.990
Pyrus pahia	Mayal	-1.863	1.814	0.953
Quercus spp.	Baj	-0.532	0.988	0.786
Quercus spp.	Khasru	2.763	1.166	0.999
Rhododendron spp.	Laligurans	-2.533	1.393	0.698
Rhus wallichii	Bhalayo	-1.954	1.899	0.956
Schima wallichii	Chilaune	-2.220	2.520	0.980
Shorea robusta	Sal	-2.608	2.996	0.982
Wendlandia coriacea	Tilke	-1.280	1.432	0.999
All other species	Mixed species	-0.280	1.510	0.930

Annex VIII: **Forest biomass and carbon stock in permanent plots at the ICIMOD Knowledge Park in 2012 and 2014**

1. Detailed strata-wise forest carbon at the ICIMOD Knowledge Park in 2012

Strata	Plot	AGTB (t ha⁻¹)	BGB (t ha⁻¹)	AGSB (t ha⁻¹)	Herb biomass (t ha⁻¹)	Leaf litter biomass (t ha⁻¹)	Total forest biomass (t ha⁻¹)	Total forest carbon (tC ha⁻¹)	Total soil carbon (tC ha⁻¹)	Total carbon stock (tC ha⁻¹)
A	B	C	d = c*0.20	E	f	g	h= c+d+e+f+g	i = h*0.47	j	k = i + l
Dense	1	83.09	16.62	7.89	0.40	3.83	111.83	52.56	182.23	234.78
Dense	3	99.66	19.93	0.00	2.66	2.09	124.34	58.44	197.24	255.67
Dense	4	325.69	65.14	1.7	0.44	2.98	395.91	186.08	159.64	345.72
Dense	5	111.50	22.30	10.35	0.29	6.39	150.83	70.89	160.65	231.54
Dense	6	114.16	22.83	4.66	0.28	2.41	144.34	67.84	161.28	229.12
Dense	7	88.29	17.66	3.98	0.16	2.13	112.22	52.74	113.06	165.81
Dense	10	110.47	22.09	13.01	0.00	3.62	149.20	70.12	149.99	220.11
Dense	11	192.14	38.43	4.14	0.49	3.14	238.35	112.02	166.22	278.24
Dense	12	111.50	22.30	1.98	0.67	1.37	137.82	64.78	167.38	232.16
Dense	14	116.30	23.26	3.43	0.35	2.69	146.03	68.64	177.60	246.24
Dense	15	181.40	36.28	0.99	0.32	3.12	222.10	104.39	179.01	283.40
Dense	18	323.28	64.66	6.88	0.34	3.67	398.83	187.45	116.16	303.61
Dense	19	125.37	25.07	11.18	0.63	2.27	164.53	77.33	197.05	274.38
Dense	20	196.55	39.31	3.05	0.09	2.21	241.21	113.37	141.21	254.58
Dense	22	67.18	13.44	4.96	0.37	1.86	87.80	41.27	219.89	261.16
Dense	23	174.27	34.85	2.44	0.35	1.99	213.90	100.53	197.42	297.95
Dense	26	236.00	47.20	0.58	0.50	3.32	287.60	135.17	124.34	259.51
Dense	29	472.71	94.54	5.00	0.00	2.87	575.12	270.31	131.14	401.45
Sparse	2	94.17	18.83	10.85	0.93	2.42	127.21	59.79	180.06	239.85
Sparse	27	122.32	24.46	1.80	0.55	4.04	153.16	71.99	181.47	253.45

2. Strata-wise forest carbon at the ICIMOD Knowledge Park in 2014

a	b	C	d = c*0.20	e	F	G	h= c+d+e+f+g	i = h*0.47	j	k = i + l
Dense	1	86.40	17.28	6.60	0.18	5.13	115.59	54.33	182.94	237.27
Dense	3	103.25	20.65	1.23	0.11	4.92	130.15	61.17	198.09	259.26
Dense	4	328.40	65.68	13.35	0.22	4.91	412.55	193.90	159.87	353.77
Dense	5	112.40	22.48	14.79	0.23	3.14	153.04	71.93	160.83	232.76
Dense	6	115.25	23.05	4.29	0.10	7.36	150.05	70.52	161.62	232.14
Dense	7	90.20	18.04	20.43	0.00	8.08	136.75	64.27	114.68	178.95
Dense	10	112.60	22.52	12.60	0.11	2.19	150.02	70.51	150.38	220.89
Dense	11	194.58	38.92	3.66	0.87	8.33	246.36	115.79	166.90	282.69
Dense	12	113.05	22.61	7.12	1.32	5.88	149.98	70.49	169.07	239.55
Dense	14	118.50	23.70	4.49	0.19	8.11	154.99	72.85	178.58	251.43
Dense	15	186.33	37.27	12.18	0.00	6.62	242.40	113.93	179.50	293.42
Dense	18	327.58	65.52	12.95	0.00	5.85	411.89	193.59	116.54	310.13
Dense	19	131.70	26.34	9.59	0.16	10.28	178.06	83.69	197.25	280.94
Dense	20	205.20	41.04	12.46	0.19	3.74	262.63	123.44	141.55	264.98
Dense	22	70.32	14.06	17.68	0.17	4.22	106.45	50.03	220.24	270.27
Dense	23	180.20	36.04	0.69	0.00	4.34	221.27	104.00	197.45	301.45
Dense	26	246.32	49.26	0.05	0.36	8.79	304.78	143.25	125.32	268.57
Dense	29	474.28	94.86	10.58	1.48	7.92	589.11	276.88	131.61	408.49
Sparse	2	102.52	20.50	0.71	0.79	2.38	126.90	59.64	180.22	239.86
Sparse	27	130.75	26.15	1.56	0.39	2.70	161.55	75.93	181.65	257.57

Annex IX: **Signs of forest disturbance recorded in permanent sample plots at the ICIMOD Knowledge Park**

SN	Year	District	Strata	Plot	Forest fire	Fodder collection	Grazing	Lopping	Timber extraction	Soil erosion and landslides
1	2014	Lalitpur	dense	1	0	0	0	0	0	0
2	2014	Lalitpur	sparse	2	0	1	0	0	0	0
3	2014	Lalitpur	dense	3	0	1	0	0	0	0
4	2014	Lalitpur	dense	4	0	1	0	0	0	0
5	2014	Lalitpur	dense	5	0	1	0	1	0	0
6	2014	Lalitpur	dense	6	0	1	0	0	0	0
7	2014	Lalitpur	dense	7	0	1	0	0	0	0
8	2014	Lalitpur	dense	10	0	1	0	1	0	0
9	2014	Lalitpur	dense	11	0	1	0	0	0	0
10	2014	Lalitpur	dense	12	0	1	0	0	0	0
11	2014	Lalitpur	dense	14	0	0	0	0	0	0
12	2014	Lalitpur	dense	15	0	1	0	0	0	0
13	2014	Lalitpur	dense	18	0	1	0	1	1	0
14	2014	Lalitpur	dense	20	0	1	0	1	0	0
15	2014	Lalitpur	dense	29	0	1	0	1	0	0
16	2014	Lalitpur	sparse	27	0	1	0	1	0	0
17	2014	Lalitpur	dense	22	0	1	0	0	0	0
18	2014	Lalitpur	dense	26	0	1	0	1	0	0
19	2014	Lalitpur	dense	19	0	1	0	0	0	0
20	2014	Lalitpur	dense	23	0	0	0	0	0	0

Note: 0 = no signs and 1 = signs recorded (or signs present)

Annex X: **Data collection sheets**

Carbon Stock Measurement Form (CSMF)

Plot No.: ____
Strata: ____
District: ____

Measurement started at: ____ (time e.g. hour : minute)
Date: / /2010 (dd/mm/yyyy)
Team leader: ____
Team members: ____

Rough sketch showing the plot:

References for the plot centre:

1. Background information

CFUG Name: ____
Forest Name: ____
Block number: ____

GPS co-ordinates
UTM-X ____ m
UTM-Y ____ m
Altitude ____ m

2. Plot informantion

	Please circle one
Forest type:	natural / plantation
Aspect:	N, S, E, W, NE, NW, SE, SW, Flat
Soil type:	clayey, loam, sandy, boulder
fire:	Yes / No
fodder collection:	Yes / No
grazing:	Yes / No
fuelwood collection:	Yes / No
timber harvesting:	Yes / No
encroachment:	Yes / No
wildlife:	Yes / No
soil erosion:	Yes / No

Please give a brief reason if the plot has been relocated from the originally given GPS position.

Vegetation type:	
Slope:	degree (average)
Soil colour:	
Soil depth:	m
Crown cover:	%
Shrub cover:	%
Grass cover:	%

Any additional information

District: ______ Strata: ______ Plot No.: ______

3. Form for herbs and grass, litter, and soil samples

1. **Herbs and grass** - measure within a 0.56m core circular plot (all vegetation below 5DBH diameter)

total weight of all herbs and grass			weight of sample grass			number on the sample packet
		gram			gram	
bag	cloth	plastic	bag	cloth	plastic	

2. **Litter** - measure within a 0.56m core circular plot

total weight of all litter			weight of sample litter			number on the sample packet
		gram			gram	
bag	cloth	plastic	bag	cloth	plastic	

3. **Soil** - measure within a 1m circular plot

0 cm - 10 cm	0 cm – 10 cm	sample no.
10 cm - 20 cm	10 cm – 20 cm	sample no.
20 cm - 30 cm	20 cm – 30 cm	sample no.

Composite soil sample (for carbon)		
total weight of the soil		
		gram
bag	white plastic	black plastic
number on the sample packet		

4. Regeneration (below 1 cm DBH) - measure within a 1 m circular plot

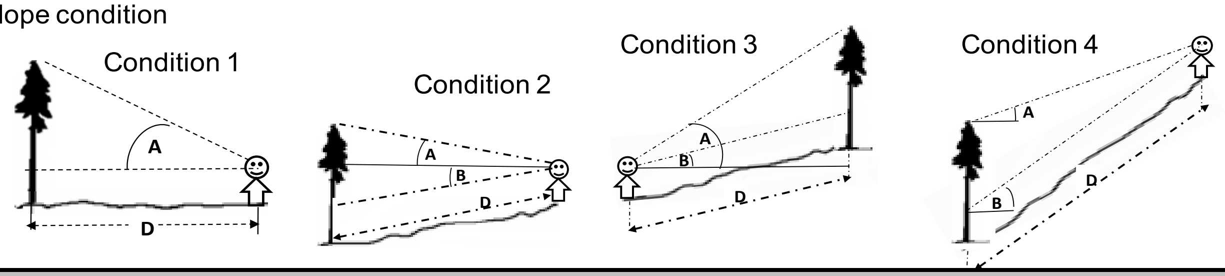
SN	Species	Total count	SN	Species	Total count
1			6		
2			7		
3			8		
4			9		
5			10		

5. Sapling (1 cm to 5 cm) - measure within 5.64 m circular plot

SN	Species	DBH (cm)	SN	Species	DBH (cm)
1		.	11		.
2		.	12		.
3		.	13		.
4		.	14		.
5		.	15		.
6		.	16		.
7		.	17		.
8		.	18		.
9		.	19		.
10		.	20		.

6. Tree - DBH and height measurements District: ______ Strata: ______ Plot No.: ______

Slope condition



SN	Species	DBH (cm) measured at breast height (1.3m)	Angles formed by top and base of the tree: top (**A**)	Angles formed by top and base of the tree: base (**B**)	Distance to the tree (m) (**D**)	Slope condition (see figure above)	Tree height (m)	Remarks
1		.	0	0	.		.	
2		.	0	0	.		.	
3		.	0	0	.		.	
4		.	0	0	.		.	
5		.	0	0	.		.	
6		.	0	0	.		.	
7		.	0	0	.		.	
8		.	0	0	.		.	
9		.	0	0	.		.	
10		.	0	0	.		.	
11		.	0	0	.		.	
12		.	0	0	.		.	
13		.	0	0	.		.	
14		.	0	0	.		.	
15		.	0	0	.		.	
16		.	0	0	.		.	
17		.	0	0	.		.	
18		.	0	0	.		.	
19		.	0	0	.		.	
20		.	0	0	.		.	

*** Appropriate slope correction has been applied and measurements are done within circular plot with horizontal diameter 8.92 m (area 250 sq.m.)**

*** All trees within the plot with DBH ≥ 5 cm have been measured**

*** The species of unidentified trees have been recorded as Sp 1...Sp 2 likewise and distinguishable characterstics are noted as comment**

8. Densiometer measurement form (DeMF)					District:		Strata:		Plot No.:	
	North		East		South		West		Average	
Grid cell	Number of Sky squares	Number of Canopy squares	Number of Sky squares	Number of Canopy squares	Number of Sky squares	Number of Canopy squares	Number of Sky squares	Number of Canopy squares	Number of Sky squares	Number of Canopy squares
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										

Consistency and completeness

It is verified that records on these forms are based on the real field measurements carried out according to the standard carbon measurement guidelines and all records are complete and consistent.

Name: Signature: Measurement end time:

Annex XI: **List of instruments, equipment, and specifications for forest measurement**

Particulars	Purpose
GPS	Boundary survey, stratification and locating plots
Base map	Plot navigation
Permanent plot establishment	
Rope	For plot boundary delineation
Linear tape	For locating plot boundary and distance measurement
Chalk	For marking the trees within the boundaries temporarily before permanent tagging and ensuring that it is measured
Metal tags for tree	For permanent marking of trees
Metal tags for plots	For showing the direction to the permanent plot from vantage points
Enamel	For numbering metal tags
Brush	For numbering metal tags
Hammer	For fixing metal tags in tree
Leaf litter and herb/grass collection	
Plastic bags	White plastic bags to collect samples and big plastic bags to collect and weigh herbs, grass, and leaf litter
Cloth bags for leaflets and twigs	As plastic bags may get torn, herbs, grass, and leaf litter should be collected in cloth bags.
Knife or sickle	For cutting herbs and grass
Weighing machine	For weighing herbs, grass, and leaf litter
Scissors	For cutting herbs and grass
Weighing machine	For weighing samples
Height and diameter measurement	
Linear tape	For measuring distance between tree and measurer
Diameter tape	For measuring diameter of the tree at breast height
Clinometer	For measuring the ground slope, top, and bottom angle to the tree
Vertex IV and Transponder	For measuring tree height and establishing circular plots without the use of tapes and clinometers

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