ICIMOD Working Paper 2015/10

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Development of Allometric Equations for *Paulownia tomentosa* (Thunb.) to Estimate Biomass and Carbon Stocks: An assessment from the ICIMOD Knowledge Park, Godavari, Nepal

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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Development of Allometric Equations for *Paulownia tomentosa* (Thunb.) to Estimate Biomass and Carbon Stocks: An assessment from the ICIMOD Knowledge Park, Godavari, Nepal

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Contents

Acronyms and Abbreviations

ANSAB	Asia Network for Sustainable Agriculture and Bioresources
C	carbon
CO_2	carbon dioxide
DBH	diameter at breast height
DF	degree of freedom
FAO	Food and Agriculture Organization of the United Nations
GPS	Global Positioning System
ICIMOD	International Centre for Integrated Mountain Development
IPCC	Intergovernmental Panel on Climate Change
m^2 ha^{-1}	square meters per hectare
m^3 ha^{-1}	cubic meters per hectare
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 stock in developing countries
SE	standard error
SWD	specific wood density (at a moisture content of 0%)
tC ha^{-1}	metric tonnes of carbon per hectare
tCO_2e ha^{-1}	metric tonnes of Carbon dioxide equivalent per hectare
UN	United Nations
UN-REDD	United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries

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This report was externally reviewed by a team of experts from India and Nepal, who have been working on allometric equations and volume table development in the region for a long time. We would like to thank the external reviewers, Dr Vishal Singh, Coordinator for the Centre for Ecology Development and Research (CEDAR), Dehradun, India; Mr Rajesh Malla, Research Officer from the Department of Forest Research and Survey, Ministry of Forest and Soil Conservation, Government of Nepal; and Mr Hasta Bahadur Thapa and Mr Prayag Tamrakar, Nepal, for their inputs and comments.

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Executive Summary

Paulownia tomentosa (Thunb.) is a fast-growing tree species that was introduced in Nepal from China in 1994 and planted in the protected forest at the ICIMOD Knowledge Park at Godavari, Kathmandu. Allometric equations have not been developed for this species in Nepal and South Asia, nor has its wood specific density or stem volume been estimated or biomass or carbon stock measured. Thus, the 20-year-old plantation at the ICIMOD Knowledge Park was selected for destructive sampling, and allometric equations were developed for measuring biomass and carbon stock in the above and below ground tree components of this fast-growing exotic species. This research report explains the comprehensive methods for developing the new allometric models, which could be used to estimate the biomass stock of *P. tomentosa* in similar physiographic and climatic zones of Nepal. It also sets out the results of applying these methods to *P. tomentosa* in the study sites at the ICIMOD Knowledge Park.

Two different plots of *P. tomentosa* planted in two different years at the ICIMOD Knowledge Park were selected for this study. The root suckers in Plot 1 were imported from China and planted in 1994. Plot 2 was established in 1999 with root suckers from the plants in Plot 1. Plantation spacing was 4 m x 4 m; however, new root sprouting occurred over time in both of the plots. Two sampling plots, each with an area of 0.1 ha (17.84 m radius circular plots) were set up for the measurement of forest vegetation parameters, especially diameter at breast height (DBH) distribution, tree density, basal area, and tree stem volume. These variables served as the basis for selecting sample trees for the development of the allometric equations and the estimation of biomass. A total of 19 sample trees with six different DBH classes were selected from the two plots. A wide range of different diameter classes were used to establish accuracy in estimating the biomass and to obtain highly significant ($P<0.001$) results from above and below ground tree component-wise (stem, branches, twigs, leaves stump roots, lateral roots, and fine roots) allometric equations of *P. tomentosa* in this study.

In order to formulate component-wise allometric equations for a specific wood density, a selective harvest sampling method was applied. A total of 247 samples of the above and below ground tree components were used to develop the allometric equations. The variables used for regression analysis were tree DBH and sample dry weight of all above ground tree components (including stem, branches, twigs, and leaves) and below ground tree components (stump root, lateral roots, and fine roots). R-core development software (2009) and the Statistical Package for Social Science (SPSS) were used to analyse the relationship between biomass and predictor variables. The mean tree density of *P. tomentosa* was 540 trees per hectare in Plot 1 and 360 trees per hectare in Plot 2. The mean basal area was 64.21 m^2 ha^{-1} in Plot 1 and 24.48 m^2 ha^{-1} in Plot 2. Similarly, the mean tree stem volume in was 67.62 m^3 ha^{-1} in Plot 1 and 53.03 m^3 ha^{-1} in Plot 2.

Highly significant ($P<0.001$) allometric equations (for estimating biomass) were obtained for both above ground and below ground tree components of *P. tomentosa* based on componenet-wise allometric equation developed through this study. A total biomass estimation equation was derived that provided the best fit (*P. tomentosa* $y=14.228x - 120.81$, $r^2=0.973$) based on the componet-wise allometric equations developed through this study.

For specific wood density (SWD), 15 tree samples with three sub-samples, each with DBH between 7.2 cm to 53 cm, were analysed. A total of 45 sub-samples were collected for further oven drying and calculations, the specific wood density of 0.268 gm cc^{-1} was obtained from the laboratory analysis (dry weight method). Comparing the results of the biomass estimation methodology suggested by previous studies (Rawat et al. 1989; Brown 1997; Rana et al. 1989; Lodhiyal et al. 2002; Chave et al. 2005; Basuki et al. 2009; Singh et al. 2011), this study also recommends a higher precision of biomass estimation in planted forest in the central highlands of Nepal.

Finally, using the newly-developed allometric equation for *P. tomentosa*, total above ground tree biomass and total below ground tree biomass was estimated. The total tree biomass (above ground and below ground) was 218.12 t ha^{-1} in Plot 1 and 82.72 t ha^{-1} in Plot 2. The total carbon stock (above ground and below ground) equivalent in Plot 1 was 102.52 tC ha^{-1}, out of which 66.67% was contributed by stem, 19.31% by branches, 1.49% by twigs, 2.90% by leaves, 6.23% by stump root, 2.73% by lateral roots, and 0.68% by fine roots. Similarly, the total carbon stock (above and below ground) in Plot 2 was 38.88 tC ha^{-1}, out of which 66.47% was contributed by stem, 18.96% by branches, 1.50% by twigs, 2.83% by leaves, 6.81% by stump root, 2.78% by lateral roots, and 0.66% by fine roots. The contribution of above ground tree components (stem, branches, twigs, and leaves) to the total biomass and carbon stock was about 90.22%, while the contribution of below ground components (stump root, lateral roots, and fine roots) was only 9.94%. Thus, the root-shoot ratio is 1:10. Using the conversion factor 3.67, the total carbon dioxide equivalent (tCO_2e) in Plot 1 was 376.24 tCO_2e ha^{-1} and in Plot 2 was 142.68 tCO_2e ha^{-1}. The results of this study showed a strong relationship between above ground tree biomass and predictor variables of DBH and specific wood density.

Introduction

Background

The emission of greenhouse gases from land use change, particularly the conversion of forestland to non-forestland and unsustainable forest management, are thought to contribute 18-20% of global greenhouse gas emissions (IPCC 2007). This increase in greenhouse gas emissions from land use change is seen as one of the underlying causes of global climate change.

In an effort to mitigate this, the initiative REDD+ (reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of carbon stock in developing countries) was proposed at the Conference of Parties (COP 13) in Bali in 2007 and formally adopted as a measure for contributing to climate change mitigation. Under the REDD+ mechanism, participating countries are required to measure and monitor the emissions of CO_2 resulting from deforestation and degradation within their borders. International debate on climate change mitigation has recognized REDD+ as an approach that creates opportunities for rural communities and farmers to participate in mitigation and adaptation actions (Dietz and Kuyah 2011).

REDD+ can be used to create carbon credits, which can generate significant income in developing countries. However, actual implementation depends on the development of accurate, verifiable methods to estimate biomass stocks and carbon sequestration rates. Nowadays, several potential payment schemes are coming into place, rewarding afforestation and reforestation activities as climate change mitigation actions. Thus, carbon in tree biomass has gained increasing significance as trees are recognized as sizeable carbon sinks for sequestering atmospheric CO_2 in both temperate and tropical areas (Houghton et al. 2001; Fang et al. 2001).

On the other hand, terrestrial biotic carbon stocks and stock changes are difficult to assess, and most current estimates are subject to considerable uncertainty due to the use of average biomass values to calculate carbon stock and its fluxes. Simultaneously, chronic disturbances and fragmentation, both natural and manmade, are major threats to forests and biodiversity in the Himalayan region (Singh 1998). Deforestation, forest disturbances, and variations in topography might also result in forest biomass that is significantly different from the average values, giving a biased result.

Biomass estimation is largely the result of a common equation applied over a large area (Houghton 2003), and estimates can vary depending on a variety of factors (i.e., age of the stand, species, and topography). Additionally, Houghton (2003) stated that errors in estimates of biomass stocks are also believed to be the result of the absence of species-specific allometric equations for trees of large diameter classes, in general, and small diameter classes, in particular. Therefore, when estimating the above and below ground biomass of a forest stand, species-specific allometric equations that consider all diameter classes of trees are preferred because trees of different species may differ greatly in tree architecture and wood density (Sundriyal et al. 1994; Sundriyal and Sharma 1996; Rai et al. 2002). The most accurate method for estimating above and below ground tree biomass is to weigh the tree biomass in the field, but this is an extremely time consuming and destructive method, so it is generally limited to small areas and small sample sizes. However, the reliability of the current estimates of biomass and forest carbon stock can be improved by applying existing knowledge on tree allometry. Recent applications and estimates of tropical forest biomass are included in scientific papers (Brown and Lugo 1982; Rawat 1983; Uhl et al. 1988; Brown et al. 1989; Rana et al. 1989; Bargali et al. 1992; Brown 1997; Lodhiyal et al. 2002; Chettri et al. 2002; Chettri and Sharma 2007; Chettri and Sharma 2009; Singh et al. 2011). Hence, the use of allometric equations is a crucial step in estimating above and below ground biomass (Crow 1978a, 1978b; Brown et al. 1989).

Allometry generally relates easily measured independent variables like DBH to other components and provides relatively accurate estimates (Phillips et al. 2002). Allometric models vary widely, but the easiest and most commonly used is a linear model in the form of $y=a+bx$, where y is the biomass, a and b are slopes and intercepts, and x is the tree diameter at breast height (Dudley and Fownes 1991). In the Nepalese context, estimates of biomass are still based on the general values of emissions provided by the Intergovernmental Panel on Climate Change (IPCC) Tier 1 approach and the existing volume-based biomass estimation models provided by Sharma and Pukkala (1990). Taking into account the biomass prediction and allocation system based on the mean tree density estimates and further developed by Sharma and Pukkala (1990), there are only a small number of species-specific biomass models available in Nepal, in comparison to species-specific volume prediction models. Moreover, no allometric models have been developed for predicting both the above and below-ground components of tree biomass (i.e., stem, branches, foliage, twigs, stump root, lateral roots, and fine roots) in Nepal. So this study aims to develop and formulate an allometric equation and methods for assessing biomass and carbon stock in the above and below ground tree components of the fast-growing tree species, *Paulownia tomentosa* (Thunb.), planted in 1994 at ICIMOD's Knowledge Park, Godavari, Kathmandu, Nepal.

Rationale

P. tomentosa is a fast-growing tree species that is highly prized as a timber tree worldwide. Its light yet strong wood is used for making a variety of musical instruments, furniture, luxury yachts, and even planes (Carpenter and Smith 1979). There is a growing interest among farmers and private land owners to invest in it to meet the increasing demand for fuelwood, fodder, and timber. Private landowners in Nepal have grown this species as an agroforestry crop on their farm land. Government and non-governmental organizations, the private sector, and communities are demanding precise information about *P. tomentosa* for cultivation on degraded, barren, and private land, as well as community forest land, to meet the demand for fuelwood, fodder, and timber, and to ultimately reduce the pressure on natural vegetation and conserve biodiversity.

Additionally, the fast growth rate makes it important for carbon sequestration. Planting *P. tomentosa* as an agroforestry crop, for example, in combination with cash crops and other non-forest timber products, could enable it to sequester high amounts of atmospheric CO_2 by locking it into both above ground and below ground parts. However, there is a dearth of information on this tree species, particularly on its biomass, carbon stock, carbon sequestration potential, wood specific density, and tree volume, especially in Nepal. Hence, there is a need to develop an allometric equation and calculate the species wood density of this exotic tree species to provide farmers, the private sector, and researchers with useful information for decision making.

Objectives

The main objective of this study was to develop allometric equations for the above and below ground components of the fast-growing deciduous *P. tomentosa* and to study the vegetation parameters to estimate tree density, basal area, and volume. More specifically, the objectives were to:

- Formulate allometric equations for above ground (stem, branches, twigs, and leaves) and below ground (stump root, lateral roots, and fine roots) components of *P. tomentosa*
- Estimate the wood-specific density of *P. tomentosa*
- Calculate the existing total biomass and carbon stock in *P. tomentosa* forest plantations at the ICIMOD Knowledge Park

Limitations

The present study was conducted within a small geographical area (i.e. two 0.1 ha plots). Thus, ecological sampling was limited to only two already established research and demonstration forest plots in Godavari, Nepal. Furthermore, the sampling covered only a single paulownia species and did not consider other flora in the study area. In addition, the unavailability of the statistically required smaller diameter class trees (<10 cm) was a major limitation. To overcome this, trees having DBH from 6–10 cm were categorized as <10 cm DBH in the study. Due to these limitations, we recommend that the use of the site-specific allometric equations developed by this study should be confined to similar physiographic regions in the middle hills of Nepal representing climatic, edaphic, topographic and biotic factors similar to those in the forests at Godavari.

Research Site

ICIMOD Knowledge Park

The ICIMOD Knowledge Park at Godavari, on the southern slopes of the Kathmandu Valley, was set up in March 1993 following the generous provision of 30 ha of land by the Government of Nepal in November 1992. The site was originally named the 'Godavari Trial and Demonstration Site', and was intended for testing and demonstration of various methodologies related to integrated mountain development and sustainable farming practices on the sloping land of the mid-hills of the Hindu Kush Himalayan region.

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 practical pendant to the often more theoretical activities of the Centre. Different technologies, farming, and other 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 the initial activities focused on the rehabilitation of degraded land systems. Since then, a considerable part of the degraded forest and shrub-land has been gradually restored to semi-natural forest. All plants are grown under organic conditions, which is without inputs of inorganic fertilizer or pesticides. The number of approaches being tested and demonstrated in the knowledge park has increased over time, with the aim of covering all the different aspects involved in an integrated approach to mountain development and agriculture. To test the growth and suitability testing of the *P. tomentosa,* two research plots were established in 1994 and 1999 in the knowledge park. Considering these two plots established for research purpose, and focusing the lack of allometric equation of this species, we aim to develop the allometric equation of *P. tomentosa*.

Paulownia plantation

P. tomentosa (Thunb.) is a pioneer deciduous tree from the family Paulowniaceae (*Scrophulariaceae*). It is commonly known as the princess tree, royal paulownia, Chinese empress tree, or foxglove tree. The tree is native to central and western China and Southeast Asia. It has been grown in China for at least 2,600 years. An ancient book entitled 'On Qin Dynasty' (221–207 BC) reported thousands of paulownia trees planted around Arfang City in China, which means that it may be the oldest tree species used by humans for plantation (Lu, and Xong 1986).

P. tomentosa is famous for its extremely fast growth, fragrant flowers, nutritious leaves, and high-priced wood. The wood is a light, yet strong, air curable, and does not warp, twist, or crack. It can be kiln dried in 24 to 48 hours and air dried in 30 to 60 days. The wood is used for pulp, paper, poles, construction materials, handicrafts, plywood, and furniture. It is also highly valued for its good resonance qualities, creating a high demand for use in the crafting of musical instruments. Likewise, it has been highly successful in agroforestry (or intercropping); the Chinese have planted it with wheat and food crops since the beginning of the tenth century. The tree is also considered an aggressive ornamental tree, as it can grow even in disturbed natural areas. It is able to rapidly remove minerals from the soil and has a high tolerance for adverse conditions; hence, it is ideally suited for use in mine reclamation and waste water management projects (Barkley 2007).

P. tomentosa is a small to medium-sized tree that attains a height of 10–30 m and is 90–150 cm in diameter at maturity. The bark is rough, grey-brown, and interlaced with shiny, smooth areas. Stems are olive brown to dark brown, hairy, and markedly flattened at the nodes. It has heart-shaped large leaves with noticeable fine hairs on the lower surfaces. The flower, which opens in the spring, consists of a purple corolla arranged in a bell-shape that resembles a foxglove flower. The fruit is a dry brown capsule with four compartments, which contain several thousand tiny winged seeds that can be dispersed by wind and water. Each seed capsule contains up to 2,000 seeds and a large tree may produce as many as 20 million seeds a year. The seed shows induced dormancy and requires light for its germination (Kays et al. 1997).

The ICIMOD Knowledge Park in Godavari has a pure plantation of medium-tall, broad-leaved, fast-growing, deciduous *P. tomentosa* trees planted in two plots (Figure 1). These two plots were established as research, demonstration, and trial plots in 1994 and 1999. The root suckers were first introduced in Plot 1 from China in 1994. Noting the growth rate and its non-invasive nature, Plot 2 was established in 1999. The root suckers planted in Plot 2 are from Nepal (i.e., taken from Plot 1). The plantation spacing was 4 m x 4 m in both plots; however, new root sprouting occurred over time in both plots.

P. tomentosa trees are mainly grown for timber, but are also used for fodder, shade, crop protection, prevention of land degradation, and as a fast-growing landscape tree. This tree species also serves the purpose of carbon sequestration. It can withstand a wide range of temperatures, but needs reliable rainfall or irrigation and good drainage conditions; shade conditions should be avoided during the growing season (Figure 2).

In 2015, the ICIMOD Knowledge Park prepared additional plots in which to plant root suckers (rhizomes). This plantation will be made in two plots: an open space and a space intercropped with citrus tree species. The purpose is to compare its growth rate in an open space and intercropped and to demonstrate a three-tier agroforestry system. The present study considered only the two plots that were planted in 1994 and 1999 (Table 1).

Table 1: **Description of *P. tomentosa* in the study sites**

Plot	Dominant species	Plantation year	Area of stand (ha)
1	*P. tomentosa* (root suckers from China)	1994	0.1
2	*P. tomentosa* (root suckers from Nepal, i.e., Plot 1)	1999	0.1

Site description

Before 1993 (prior to the establishment of the ICIMOD Knowledge Park), the natural forests at the research site primarily consisted of *Schima wallichii, Castanopsis* spp., *Michelia* spp., *Alnus nepalensis*, *Rhododendron arboreum*, and *Litsea oblonga*. However, these were destroyed by unsustainable harvesting and the excessive removal of the most useful species for fodder, fuelwood, timber, and charcoal making. With the generous support of the Government of Nepal, ICIMOD received 30 hectares of highly-degraded hill in 1993 for restoration purposes. With continuous conservation efforts, the existing vegetation has almost all been naturally regenerated, and the tree species are dominated by mixed deciduous and evergreen broadleaf species. The vegetation cover shows natural forest on steep slopes (mainly *Carpinus* spp., *Castanopsis* spp., and *Arundinaria* spp., *Quercus* spp., *Michelia* spp., and *S. wallichii*), shrub land on mixed slopes (mainly *Cleyera* spp., *Laurel* spp., *Quercus* spp., *A. nepalensis, Castanopsis* spp., and *S. wallichii*), and shrub and bushes on the valley floor (*Rubus,* spp., *Eupatorium* spp., *Pinus* spp., *S. wallichii*, *Michelia* spp., *A. nepalensis*, and *Castanopsis* spp.).

The ICIMOD Knowledge Park lies in the Pulchowki watershed area and is located 15 km southeast of the Kathmandu Valley. It falls under the administrative jurisdiction of Godavari Municipality, Ward No. 5, Lalitpur District. It lies between latitude 27° 35′ 19″ and 27° 35′ 41″N and longitude 85° 23′ 16″ and 85° 23′ 44″E, with an altitude range of 1,540–1,800 metres above sea level (masl) and a slope gradient range from almost zero degrees to more than 60 degrees in parts of the upper forest zone. The soil varies from clay loam to sandy and silty clay loams that are rich in forest humus, and from streambed sandy alluvial soil to ridgetop shallow dry soil. The climate is subtropical, warm temperate, with a mean annual temperature of 17.2°C. The temperature ranges from -0.9°C to 33.8°C and the relative humidity is 76%. Most of the precipitation occurs during the monsoon and the average annual rainfall is about 2,000 mm. The total area of the park is about 30 hectares and it is surrounded by the Godavari Kunda Community Forest to the northeast and Diyale Community Forest to the southwest.

The total area of the study site, i.e., the two *P. tomentosa* planted plots, is 0.2 hectares. The coordinates of the two plots are latitude 27° 25′ 40″N and longitude 85° 23′ 18.7″ and latitude 27° 35′34.2″N and longitude 85° 23′ 14.2″. These two plots were considered for the development of allometric equations. The location of the plots are shown in the map in Figure 1.

Figure 1: **Map of research sites at ICIMOD Knowledge Park, Godavari, Kathmandu**

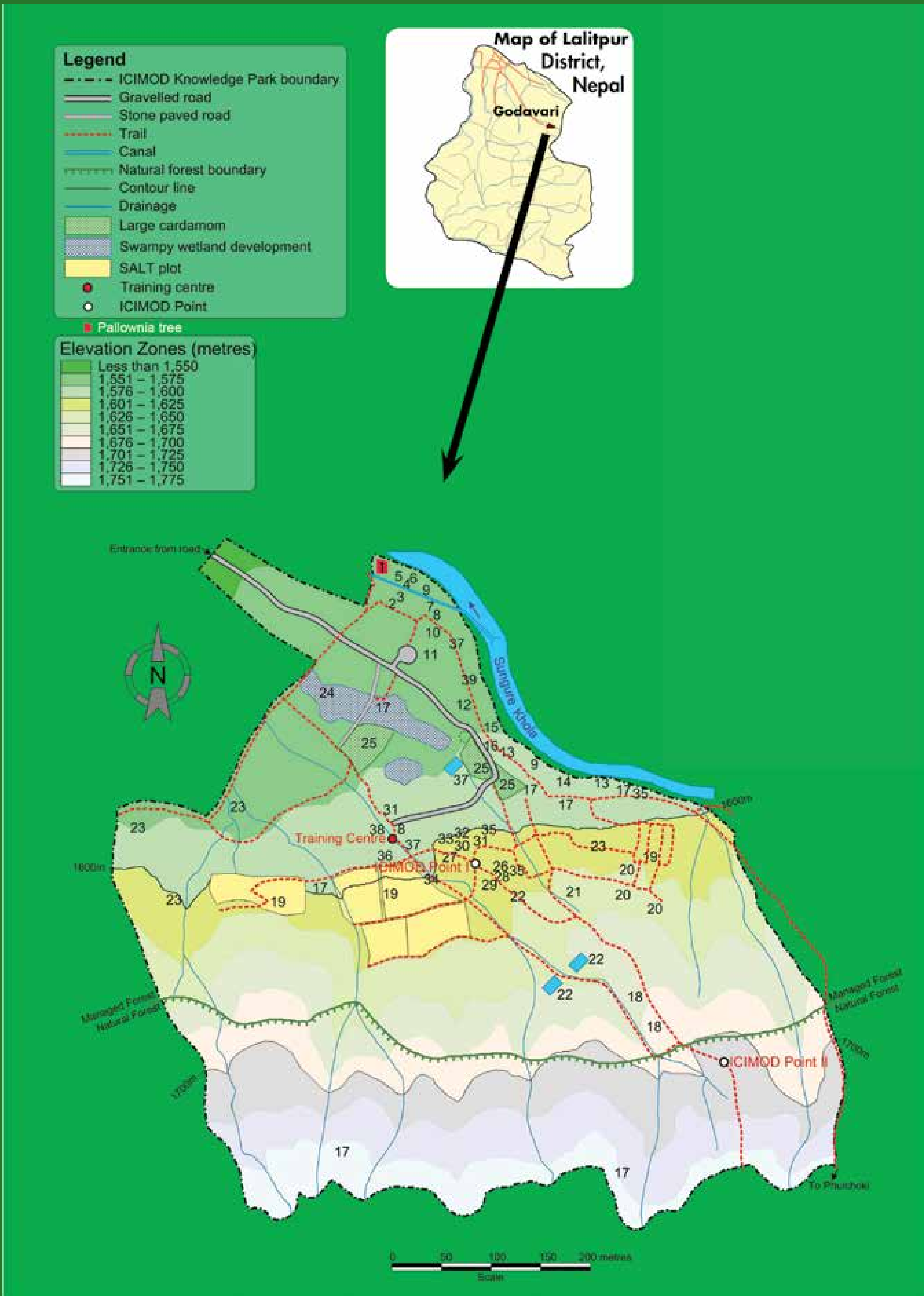


Figure 2: ***P. tomentosa*** **plantations at the ICIMOD Knowledge Park**

Methodology, Procedure, and Study Approach

This chapter discusses the approach and methodology for developing allometric equations and estimating wood-specific density, along with the measurement of biomass and carbon stock of *P. tomentosa*. It also includes a description of the different tools and techniques applied during data collection and analysis.

This study was conducted jointly by an independent researcher, his team, and the ICIMOD REDD+ team. For collecting the samples, the study team referred to the 'Manual for building tree volume and biomass allometric equations' developed by FAO and CIRAD (Picard et al. 2012), 'Guidelines for establishing regional allometric equations for biomass estimation through destructive sampling' developed by World Agroforestry Centre (ICRAF 2011), 'Guidelines on destructive measurements of forest biomass estimation' developed by FAO (2011) for the UN-REDD Viet-Nam Program, and the carbon Fund Methodological Framework (2014) designed by the Forest carbon Partnership Facility (FCPF). Furthermore, for the detailed measurement of forest biomass and carbon stock, the Asia Network for Sustainable Agriculture and Bioresources (ANSAB), ICIMOD, and the Federation of Community Forestry Users Nepal (FECOFUN) developed Forest carbon Stock Measurement Guidelines (Subedi et al. 2010) developed was followed.

For forest biomass and carbon stock estimation, a step-wise procedure was followed, using internationally recognized standards of forest carbon inventory principles (Table 2). In the following sections we describe the methodologies and tools used for sampling, data collection, and analysis.

Table 2: **IPCC's good guidance principles for carbon accounting**

Accurate and precise	• Accuracy is how close estimates are to the true value; accurate measurements lack bias and systematic error. • Precision is the level of agreement between repeated measurements; precise measurements have lower random error.
Comparable	• Data, methods, and assumptions applied in the accounting process must be those with widespread consensus and which allow for meaningful and valid comparison between areas.
Complete	• Accounting should be inclusive of all relevant categories of sources and sinks and gases. If carbon pools are excluded, documentation and justification for their omission must be presented.
Conservative	• Where accounting relies on assumptions, values, and procedures with high uncertainty, the most conservative option in the biological range should be chosen. Conservative carbon estimates can also be achieved through the omission of carbon pools.
Consistent	• Accounting estimates for different years, gases, and categories should reflect real differences in carbon rather than differences in methods.
Relevance	• Recognizing that tradeoffs must be made in accounting as a result of time and resource constraints, the data, methods, and assumptions must be appropriate to the intended use of the information.
Transparent	• The integrity of the reported results should be able to be confirmed by a third party or external actor. This requires clear and sufficient documentation.

Source: IPCC 2006

Orientation training and field planning

First of all, to ensure consistency during the collection of data and field measurements, hands-on training was provided to the forest technicians and field staff of the ICIMOD Knowledge Park. The forest technicians and field staff were thoroughly trained on techniques for field data collection and sample collection for the development of allometric equations for *P. tomentosa*. The trained forest technicians were the principal technical persons who assisted in subsequent trainings and with the implementation of forest carbon stock assessment in the field.

Detailed field planning was conducted after completion of the orientation and hands-on training. The planning process was participatory and all field crew members and forest technicians were involved to finalize the schedule and field activities, including, for example, the arrangement of the field equipment, mobilizing sufficient and skilled human resources for data collection, destructive harvesting and sampling, sample measurement, storage, and, finally, carriage of samples to the laboratory. This field planning process was important to ensure the efficient and timely completion of the field work and data collection.

Checklist of equipment and materials

All of the required equipment and materials were collected before going to the field and every instrument and piece of equipment was prepared, checked, and calibrated beforehand. The operational team ensured that the instruments were functioning, so that the field work could be conducted smoothly. A complete checklist (Annex II) of instruments was on hand during the field work so that none of them were lost; this checklist was useful in keeping track of the instruments as the field team moved from one plot to the other to take measurements.

Human resources management

A team of eight members was formed well in advance of the first field work to ensure realistic and complete data collection. Two professional forest technicians were hired for overall supervision. An experienced person was also hired from the Department of Forest Research and Survey (DFRS) during the entire field work for the harvesting and logging of the *P. tomentosa* trees. These forest technicians led the whole field study, as they had detailed knowledge on the methodology and comprehended the importance of the tiniest details of the work, as well as being able to operate all of the equipment properly. In addition, a short orientation programme was provided to the other team members from the ICIMOD Knowledge Park prior to each field work to ensure the quality of data collection.

Tree harvesting for allometric equations and estimating specific wood density

This section of the report sets out the key procedures used to carry out the selective harvest sampling and tree selection, and sample preparation and measurement for development of the allometric equations and estimation of specific wood density. The allometric equation developed was later used to calculate biomass and carbon stocks based on the field work carried out at the ICIMOD Knowledge Park in 2014.

Preparation of field equipment and materials

Based on the previously developed field work plan, the required equipment and materials were prepared before the field work. The following field equipments and materials were gathered and used during the collection of field data.

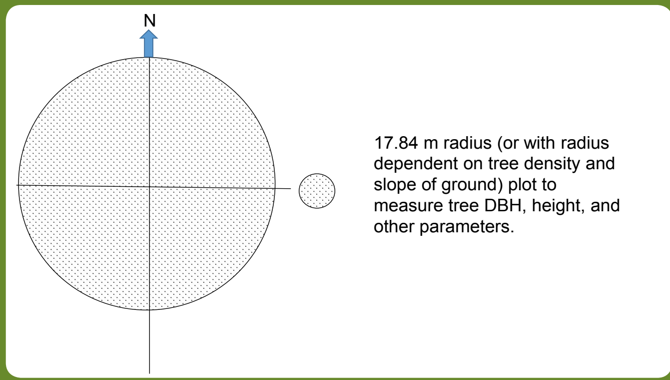
- GPS
- Silva compass
- Vertex IV and Transponder linear measurement tape (50 or 100 m)
- DBH measurement tape
- Saw (bow saw and hand saw)
- Digital measuring scale 10–500 kg, with 0.1 kg precision
- Hanging scale up to 10 kg, with 0.05 kg precision
- Chemical scale 600 g for weighing samples, with 0.01 g precision
- Other materials: 1.3 m pole, ladder, white paint, markers, poly bags, ropes and field data forms for record keeping

Sample plot establishment

The size and shape of the sample plot was a tradeoff between cost and the accuracy of the measurement. A typical sample plot of 0.1 ha was established for the *P. tomentosa* plantations randomly at two different sites (Figure 1), based on the species area curve method. The plot was circular in shape with a radius of 17.84 m (Figure 3), demarcated with the help of Vertex IV and Transponder measurement tapes.

A standard plot sampling method was applied to establish the sample plots for measurement and destructive harvesting. The sample plots were set up on less disturbed forest areas where large sized, vigorous, and healthy trees were available.

Figure 3: **Size and shape of sample plot for data collection**



Measurement of tree diameter and height

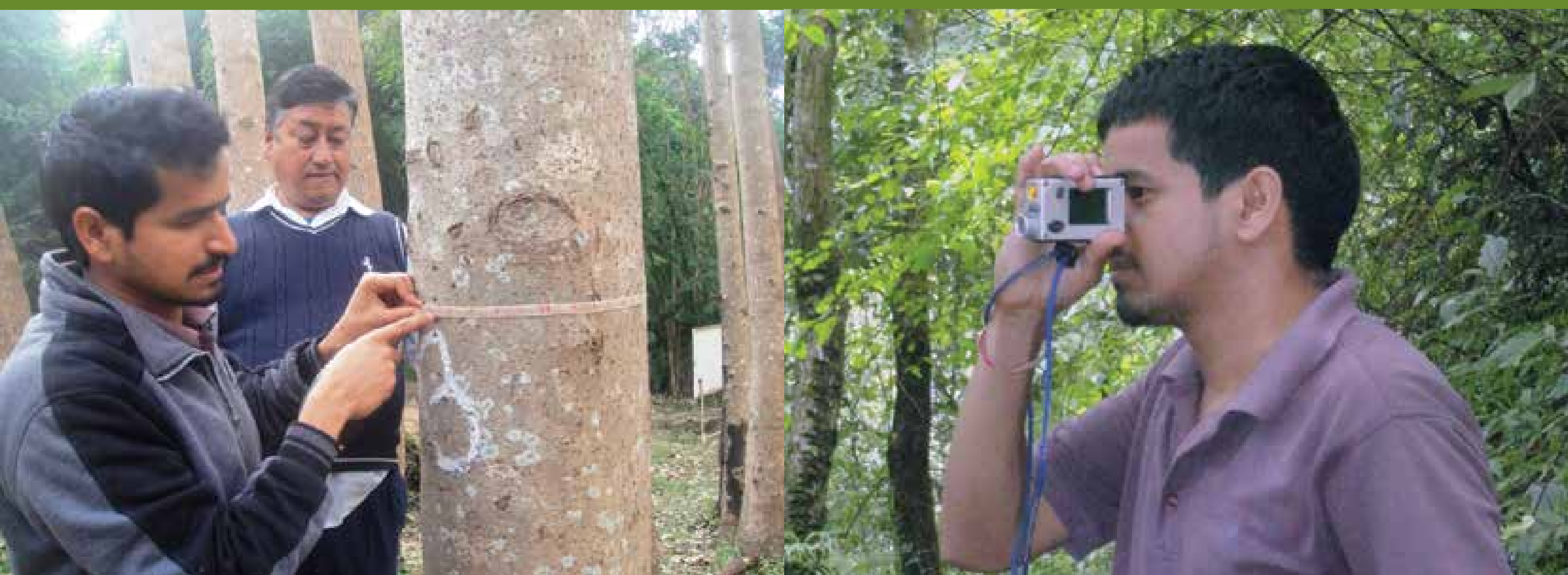
All live trees situated within the sample plots of 0.1 ha size were marked and numbered. Trees were marked starting from the edge and moving in a north direction, working inwards to prevent accidental double counting. Each tree was then recorded individually together with its species classification. There were altogether 90 trees in Plots 1 and 2 (54 in Plot 1 and 36 in Plot 2). 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. The diameter of the marked trees was measured at breast height (DBH), along with the height of the tree. The DBH was measured using a diameter tape, whereas a Vertex IV and Transponder measurement types were used for height measurement to calculate the standing tree stem volume (Figure 4). The collected data were used to analyse the distribution of DBH classes and calculate the density, basal area, and standing tree volume. The tree density and basal area of the standing trees within the sample plots were estimated following Saxena and Singh (1982). Finally the tree vegetation data was analysed using methods from Curtis and McIntosh (1950), Hanson and Churchill (1961), and Zobel et al. (1987).

Harvesting of trees

Upon completion of the DBH and tree height measurement of the numbered trees within the two sample plots, the following steps were followed to select a total of 19 trees from the two plots for felling and preparing samples and sub-samples:

Step 1. First the DBH data of all trees from two sample plots were entered into an Excel spreadsheet and classified into six DBH classes with an interval of 10 cm. The assigned DBH classes are: (i) <10 cm, i.e., (6–10 cm),

Figure 4: **DBH measurement and use of Vertex IV and Transponder**



(ii) 10.1–20 cm, (iii) 20.1–30 cm, (iv) 30.1–40 cm, (v) 40.1–50 cm, and (vi) > 50 cm. Data on the length of the tree stem from stump to the point where the diameter is less than 6 cm were not available in the study area. Thus, we considered trees with DBH of 7–10 cm as <10 cm class.

Step 2. A total of 19 trees were randomly selected from the six DBH classes. Of the 19 trees, there were four from <10 cm DBH class, four from 10.1–20 cm, four from 20.1–30 cm, three from 30.1–40 cm, three from 40.1–50 cm, and one from >50 cm DBH classes were randomly selected for felling. Modern logging equipment was used to fell the trees.

Step 3. The principles of reduced impact logging (RIL) (Sist 2000) were applied in the field to reduce possible negative environmental impacts. Likewise, standard forestry harvesting practices (Kantola, and Harstela 1988) were followed to eliminate or control the human hazards and forest damage caused by tree felling operations, including: determining felling direction, use of a top sear cut, use of a bottom sear cut, small lateral cuts – to prevent trimming out of fibre, a main felling cut or back cut – allowing slightly higher than bottom of scar, and leaving enough wood as a hinge.

Step 4. The harvested sample trees were cut into different sized logs, varying in length from 1 to 2 m. The whole harvested trees were then categorized into seven different tree components: stem, branches, twigs, leaves, stump root, lateral roots, and fine roots. Component-wise total fresh weight was taken after separating the 19 trees into: above ground tree components (stem, branches, twigs, and leaves) and below ground tree components (stump root, lateral roots, and fine roots) (see Rawat 1983; Rana et. al. 1989; Lodhiyal et al. 2002; Chave et al. 2005; Singh et al. 2011). The sub-samples ranging from 10 to 5,000 gm were sent to the laboratory for oven dry biomass estimation.

Sample preparation for the laboratory

The homogenously mixed and representative samples of the above and below ground tree components were sent to the laboratory to estimate the oven dry weight. The component-wise dry weight results obtained from the laboratory analysis were put into the various statistical models (linear, logarithmic after transformation, quadratic, power, cubic, and polynomial). The best-fit linear model was then applied to obtain the component-wise biomass for each diameter class. The following steps were carried out.

Sample for dry mass analysis

Three sub-samples from each sample tree for each above ground tree component (stem, branches, twigs, and leaves) and below ground tree component (stump root, lateral roots, and fine roots) were collected for dry mass analysis (Figure 5). The following steps were performed:

Step 1. Three discs were taken from the bottom, middle, and top part of the stem as three stem sub-samples. Similarly, to sample the branches, three small disks were taken from small, medium, and large parts of the branches. The same process was followed for the stump root, while we took only one sub-sample for

Figure 5: **Sub-samples collected for dry mass analysis**

twigs, leaves, and lateral roots. Hence, there were a total of 13 sub-samples for each harvested tree and, thus, a total of 247 sub-samples were analysed for all 19 trees.

Step 2. For the below ground tree samples, sub-samples of the stump root were taken from different positions on the stump root (base, middle, and top parts); however, this was not done in the case of lateral roots and fine roots.

Step 3. Segregated sub-samples of the above and below ground tree components of samples trees (mainly the stem, branches, twigs, leaves, stump root, lateral roots, and fine roots) were put into poly bags, marked, and tied tightly to prevent evaporation.

Step 4. Each sample and sub-sample was then weighed carefully using different scales (digital measuring scale, hanging scale and chemical scale) on the same day of felling to determine the exact fresh weight in the field and then sent to the laboratory within a few hours.

Samples for wood density analysis

For wood density analysis, sub-samples of 45 wood discs were selected from stem components of trees, with six different diameter classes from 15 of the total felled trees, with proportionate selections from each diameter class. The sampling procedure followed was:

Step 1. The sampling positions were marked at stump level (0.0 m) and at 1/4 of stem length, 1/2 of stem length, and 3/4 of stem length. The stem length varied from stem to stem for the felled trees.

Step 2. Three wood discs with varied thickness (e.g., 2 to 10 cm) were taken from each marked position on the tree stem (base, middle, and top).

Step 3. All samples for allometric equations and wood density analysis were labelled for identification. The labelling for wood density analysis included: the plot code; sample tree code; and sample position (0.0 m, 1/4 of stem length, 1/2 of stem length, and 3/4 of stem length).

Laboratory analysis

All samples were sent to the Nepal Agricultural Research Council laboratory in Kathmandu for analysis. A total of 114 samples and 38 sub-samples of above ground and 38 samples and 57 sub-samples of below ground tree components of *P. tomentosa* were analysed at the laboratory. The dry weight of the component-wise samples was obtained using an oven drier at temperature of 105°C at least for 72 hours until the samples reached a constant weight. Likewise, basic wood densities for the wood discs were obtained at moisture content of 0%. The following equipment was used for the analysis:

- Drying oven
- Laboratory scale
- Measuring cylinder (5,000 ml capacity)

Data entry and analysis

After completion of the field work and laboratory analysis, data entry and analysis was carried out for the development of the allometric equations and wood specific density. All the relevant data from the field were entered into an Excel spreadsheet, while considering quality assurance and quality control. This included data from two plots of *P. tomentosa* plantation, with general information and measurements such as vegetation composition, height, DBH, number of trees in different DBH classes, component-wise fresh biomass weight, oven dry weight, and wood density measurements. For the quantitative data analysis, tree density, basal area, and stem volume were calculated using the method described by Zobel et al. (1987) and Sharma and Pukkala (1990). These are briefly described below.

Tree density

The per hectare tree density of the *P. tomentosa* plantation at the ICIMOD Knowledge Park was calculated using the following equation (i) provided by Zobel et al. (1987):

$$\text{Density (no./ha)} = \frac{\text{No. of individuals of a species}}{\text{Total no. of plots} \times \text{area of each plot}} \times 10{,}000 \qquad \text{(i)}$$

Tree basal area

The basal area of a tree is the ground actually penetrated by the stems (Hanson and Churchill 1961). It is one of the characteristics that determine the dominance of the tree. The basal area of the *P. tomentosa* stand was calculated using the following equation (ii):

$$\text{Basal area } (m^2\, ha^{-1}) = \frac{\pi \times (\text{DBH})^2}{4} \qquad \text{(ii)}$$

Tree stem volume

The tree stem volume equations developed by Sharma and Pukkala (1990) were used to estimate the volume of standing trees. The following equation (iii) was used for volume estimation:

$$\ln(v) = a + b \ln(d) + c \ln(h) \qquad \text{(iii)}$$

where,

In= Natural logarithm to the base 2.71828

d= DBH in cm

h= Height of the tree in m

a, b and c are parameters

Total dry weight for each component of sample tree

The total dry weight for each component of sample tree is calculated based on the total fresh weight of each component measured in the field and the ratio of dry weight to fresh weight calculated for the respective component in the laboratory. The following equation (iv) gives the total dry weight (TDW) for calculation of dry mass of the above and below ground tree components. The six diameter classes and the mean and individual tree component-wise dry weight of *P. tomentosa* at the ICIMOD Knowledge Park are provided in Annexes VI and VII, respectively.

$$\text{Individual tree components} = \frac{W_{field}}{A} \times \frac{W_{sub\text{-}sample\ dry\ wt}}{W_{sub\text{-}sample\ wet\ wt}} \times 10{,}000 \qquad \text{(iv)}$$

where,

Individual tree components	=	biomass of individual tree component [t ha^{-1}]
W_{field}	=	weight of the fresh field sample of individual tree sampled within an area of size A; total fresh weight of each component from all sample trees (kg)
A	=	total area of plots in which biomass data of each component were collected (m^2)
$W_{sub\text{-}sample\ dry}$	=	weight of the oven-dry sub-sample of individual tree components taken to the laboratory to determine moisture content (kg)
$W_{sub\text{-}sample\ wet}$	=	weight of the fresh sub-sample of individual tree component taken to the laboratory to determine moisture content (kg)

The carbon content calculated in each component of the tree is then estimated by multiplying the biomass value of individual tree components with the default carbon fraction 0.47 recommended by IPCC (2006).

Specific wood density

The specific wood density (SWD) of *P. tomentosa* was analysed using the oven dried wood discs for each sample tree and calculated using the following equation (v):

SWD = SDWc/SV (v)

Where,

SWD = Specific wood density in (gm/cm^3)

SDWc = Dry weight of a sub-sample in (gm)

SV = Dolume of sub-samples in (gm)

Regression analysis and development of equations

The data obtained from oven drying all the tree components provided the total dry weight of all the samples from the above and below ground tree parts of individual sample trees in all diameter classes, which were then statistically computed following the methods stated by previous researchers (Rawat 1983; Rana et. al. 1989; Singh et. al 2011). The constants were put into the linear equation to obtain a single biomass equation and one for each individual tree component. The most commonly used linear model is: $y=a+bx$, where y is the biomass and x is the tree diameter at breast height (Dudley and Fownes 1991). After completion of the regression analysis, the best-fit allometric equation was assessed, and the equations with the highest correlation index that were highly significant and with the smallest error for biomass estimation were selected for measurement of each of the above and below ground tree components.

Tree biomass and carbon stock measurement

The biomass for the different tree components from the various diameter classes of *P. tomentosa* was estimated using parameters such as DBH and the allometric equations developed in this study (see Table 7). The biomass of the different tree components (stem, branches, twigs, leaves, stump root, lateral roots, and fine root) were then summed to calculate the total tree biomass of the *P. tomentosa* stand. The following newly formulated linear equation (vi) was used.

$y= a+bx$ (vi)

where,

y= biomass of each tree component (kg)

a= intercept

b= slope

x= diameter at breast height (1.30 m)

The biomass value in kilogrammes for each component was then converted first into tonne sand then into the tonnes per hectare. Thereafter, the biomass values were converted into carbon by multiplying them with the default carbon fraction of 0.47 recommended by IPCC (2006). Thus, the calculated tonnes of carbon were converted into Carbon dioxide equivalent (tCO_2e) by multiplying the carbon value by 3.67, as suggested by Pearson et al. (2007).

Results and Discussion

General forest parameters

Tree density

The total tree density of *P. tomentosa* was found to be 540 trees per hectare in Plot 1 and 360 trees per hectare in Plot 2. The difference in tree density in these two plots is the result of new roots sprouting over time in between the tree spacing of 4 m x 4 m and the age difference of the plots (21 years versus 16 years). Plot 1 shows more canopy cover than Plot 2. In Plot 1, the mean tree diameter and height are 36.89 cm and 22.48 m, respectively. In Plot 2, the mean tree diameter and height are 24.71 cm and 15.58 m, respectively (Table 3). The diameter and tree height of *P. tomentosa* from each of the plots are presented in Annex IV. As the plots are different in age, the mean tree height of these two plots showed a variation. The six tree diameter classes of *P. tomentosa*, mean DBH, and mean height in Plot 1 and Plot 2 at the ICIMOD Knowledge Park are presented in Annex V.

Table 3: **Mean tree DBH and height of *P. tomentosa* stands in the study sites**

Plot	Mean tree DBH (cm)	Mean tree height (m)	Tree density (per ha)
1	36.89	22.48	540
2	24.71	15.57	360

The DBH distributions followed a right-skewed trend in both of the sites (Figure 6), which indicates that most of the trees in all strata are young and there is high potential to enhance tree biomass and carbon stock.

The proportion of trees having diameter (DBH class) between 40–50 cm was 14.4%, between 30–40 cm was 26.7%, between 20–30 cm was 24.4%, between 10–20cm was 15.6%, and < 10 cm and very old DBH >50 cm were 2.2% and 16.4%, respectively (Figure 7).

Figure 6: **Skewness in tree DBH for *P. tomentosa* at ICIMOD Knowledge Park**

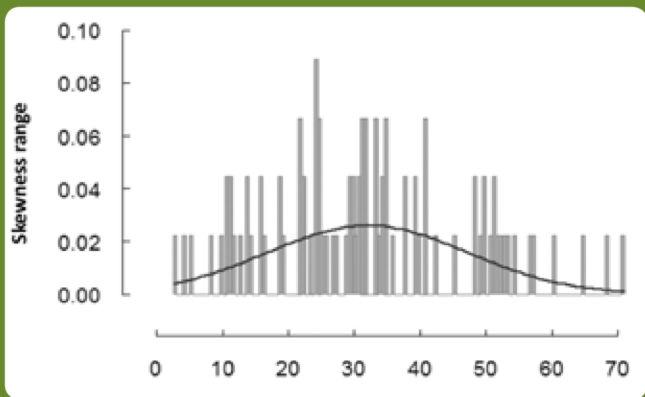
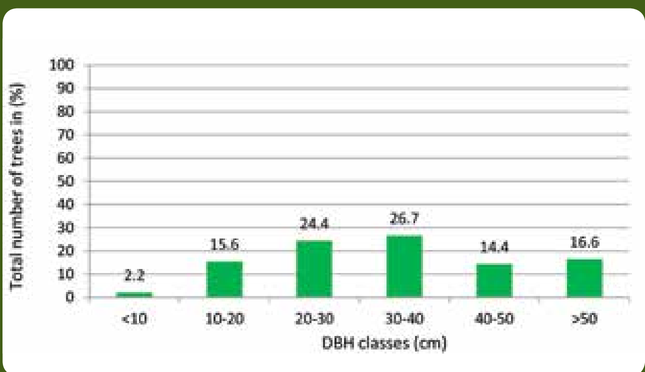


Figure 7: **Diameter class distribution in *P. tomentosa* stands at ICIMOD Knowledge Park**



Growing stock

The total tree basal area of *P. tomentosa* in Plot 1 was 64.21 (m^2 ha^{-1}) and in Plot 2 was 24.48 (m^2 ha^{-1}). The total tree stem volume of *P. tomentosa* in Plot 1 was 67.62 $m^3 ha^{-1}$ and in Plot 2 was only 53.03 m^3 ha^{-1}. The mean stem volume in both the *P. tomentosa* stands was 60.32 m^3 ha^{-1}. The overall growing stock of the *P. tomentosa* plots at ICIMOD Knowledge Park was found to be good (Table 4).

Allometric equation/model

Highly significant (P<0.001) allometric equations were obtained for above ground (stem, branches, twigs, and leaves) and below ground (stump root, lateral roots, and fine roots) tree components of *P. tomentosa* (Table 5). In addition, for estimating total biomass, one general biomass equation was developed and tested (i.e. *P. tomentosa*, y=14.228x -120.81), and it was also highly significant (P<0.001) and showed the highest coefficient of determination, or the coefficient of multiple determination for multiple regression (r^2=0.973), than all of the other component-specific allometric equations.

Table 4: **Basal area and stem volume of *P. tomentosa* in the study sites**

Plot	Tree basal area (m^2ha^{-1})	Tree stem volume (m^3ha^{-1})
1	64.21	67.62
2	24.48	53.03

Table 5: **Allometric equations developed for each tree component of *P. tomentosa* in the study sites**

Species	Tree component	Intercept (a)	Slope (b)	r^2	Component-wise allometric equations
P. tomentosa y=14.228x –120.81, r^2=0.973 (Considering y=a+bx); where y=biomass of each tree component, a=slope, b=intercept, x=DBH (as an independent variable) and r^2=coefficient of determination	Stem	-81.908	9.5225	0.971	y=9.5225x –81.908
	Branches	-25.720	2.8120	0.924	y=2.812x –25.720
	Twigs	-1.7423	0.2105	0.932	y=0.2105x –1.7423
	Leaves	-3.9895	0.4259	0.954	y=0.4259x –3.9895
	Stump root	-3.4669	0.7758	0.966	y=0.7758x –3.4669
	Lateral roots	-2.9874	0.3802	0.969	y=0.3802x –2.9874
	Fine roots	-0.9919	0.1010	0.943	y=0.101x –0.9919

Component-wise allometric equations

Allometric equation for stems

The developed allometric equation for stem components was highly significant (i.e., y=9.5225x –81.908, r^2=0,971), with an observed positive correlation between tree DBH and oven dry weight of stem components. Further, a linear regression model was fitted, which revealed a highly significant relationship at P<0.001 and r^2=0.971 (Figure 8). The summary output of stem components is given in Table 6.

Allometric equation for branches

The developed allometric equation for branch components was highly significant (y=2.812x –25.720, r^2=0.924), with an observed positive correlation between tree DBH and oven dry weight of the branches component. Further, a linear regression model was fitted, which revealed a highly significant relationship at P<0.001 and r^2=0.924 (Figure 9). The summary output of branch components is given in Table 7.

Allometric equation for twigs

The developed allometric equation for twig components was highly significant (i.e., y=0.2105x

Figure 8: **Linear relationship between tree DBH and oven dry stem components**

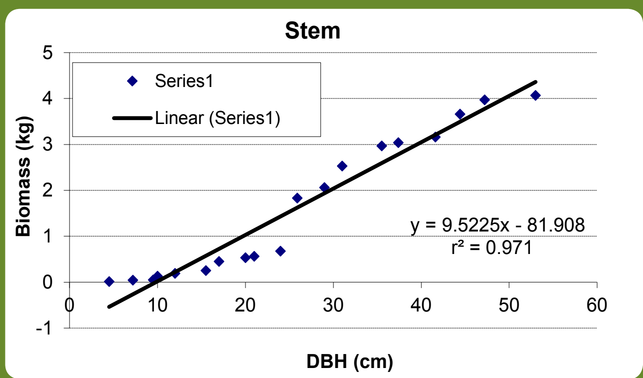


Figure 9: **Linear relationship between tree DBH and oven dry branch components**

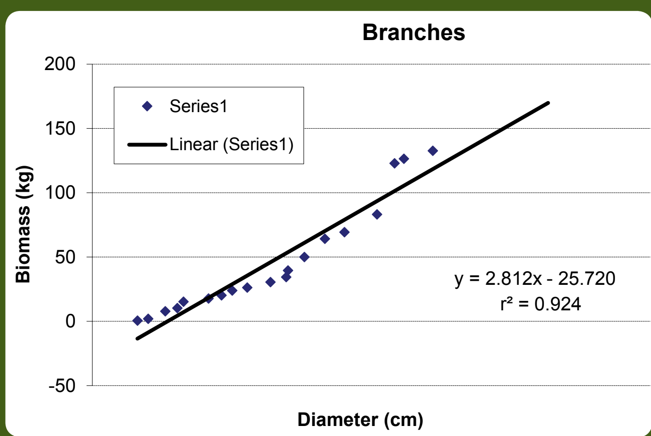


Table 6: **Summary output of stem components**

Estimate	Standard error (SE)	Residual SE	Multiple r-squared	Adjusted r-squared	T-value	F-statistic	Degree of freedom (DF)	Pr>[t]	P_value
a= –81.9220	5.7081	11.57	0.971	0.9697	-7.078	578 on 1	17	1.85e-06***	< 1.45e^{-1}4
b= 9.5226	2.083								

*** highly significant (at 0.001)

Table 7: **Summary output of branch components**

Estimate	SE	Residual SE	Multiple r-squared	Adjusted r-squared	T-value	F-statistic	DF	Pr>[t]	P_value
a=-25.72	5.7081	12.05	0.9242	0.9197	-4.506	207.2 on 1	17	0.000312***	< 5.938e^{-1}1
b=2.8120	0.1953								

*** highly significant (at 0.001)

Table 8: **Summary output of twig components**

Estimate	SE	Residual SE	Multiple r-squared	Adjusted r-squared	T-value	F-statistic	DF	Pr>[t]	P_value
a=–1.7423	0.400	0.8446	0.9329	0.929	-4.506	236.5 on 1	17	0.00043***	< 2.084e^{-1}1
b=0.2105	0.013								

*** highly significant (at 0.001)

–1.7423, r^2=0.932), with an observed positive correlation between tree DBH and the oven dry weight of the twig components. Further, a linear regression model was fitted, which revealed a highly significant relationship at P<0.001 and r^2=0.932 (Figure 10). The summary output of twig components is given in Table 8.

Allometric equation for leaves

The developed allometric equation for leaves was highly significant (i.e., y=0.4259x –3.9895, r^2=0.954), with an observed positive correlation between tree DBH and the oven dry weight of the leaves component. Further, a linear regression model was fitted, which revealed a highly significant relationship at P<0.001 and r^2=0.954 (Figure 11). The summary output of leaf components is given in Table 9.

Figure 10: **Linear relationship between tree DBH and oven dry twig components**

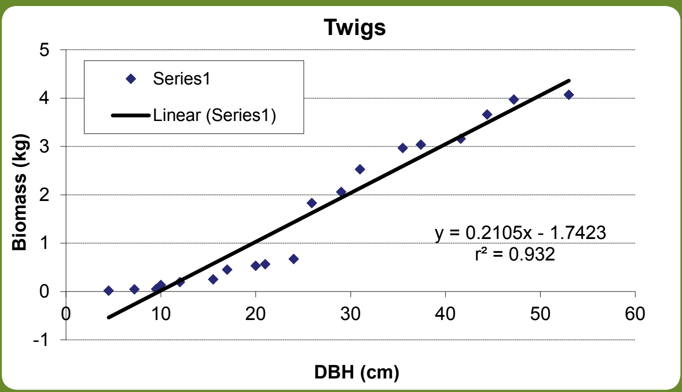


Figure 11: **Linear relationship between tree DBH and oven dry leaf components**

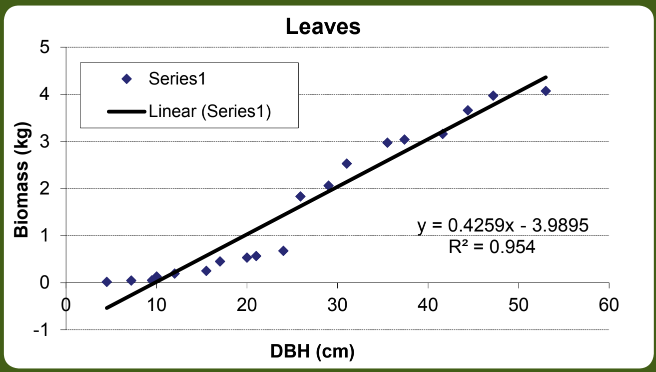


Table 9: **Summary output of leaf components**

Estimate	SE	Residual SE	Multiple r-squared	Adjusted r-squared	T-value	F-statistic	DF	Pr>[t]	P_value
a=-3.9895	0.659	0.8446	0.9544	0.9581	-6.051	336.2 on 1	17	1.30e-05***	< 7.71e-13
b=0.4259	0.022								

*** highly significant (at 0.001)

Allometric equation for stump root

The developed allometric equation for stump root component was highly significant (i.e., $y=0.7758x - 3.4669$, $r^2=0.966$), with an observed positive correlation between tree DBH and oven dry weight of the stump root components. Further, a linear regression model was fitted, which revealed a highly significant relationship at $P<0.001$ and $r^2=0.966$ (Figure 12). The summary output of stump root component is given in Table 10.

Allometric equation for lateral roots

The developed allometric equation for later root components was highly significant (i.e., $y=0.3802x - 2.9874$, $r^2=0.969$), with an observed positive correlation between tree DBH and oven dry weight of the lateral root component. Further, a linear regression model was fitted, which revealed a highly significant relationship at $P<0.001$ and $r^2=0.969$ (Figure 13). The summary output of lateral roots component is given in Table 10.

Allometric equation for fine roots

The developed allometric equation for fine roots was highly significant (i.e., $y=0.101x - 0.9919$, $r^2=0.943$) with the observed positive correlation between tree DBH and oven dry weight of the fine roots component. Further, a linear regression model was fitted, which revealed a highly significant relationship at $P<0.001$ and $r^2=0.943$ (Figure 14). The summary output of fine roots component is given in Table 12.

Specific wood density

Based on the analysis of *P. tomentosa* from oven dried sample weights and the volume of dried wood discs from each sample tree, the specific wood density (oven dried) was estimated to be 0.268 gm/cc^{-1}, which is equivalent to 268 kg m^{-3} (Table 13). Based on the average wood specific density value, we can say that the wood is a light wood, similar to *Bombax malabaricum* (368 kg m^{-3} air dried wood specific density), as reported by Sharma and Pukkala (1990).

Figure 12: **Linear relationship between tree DBH and oven dry stump root components**

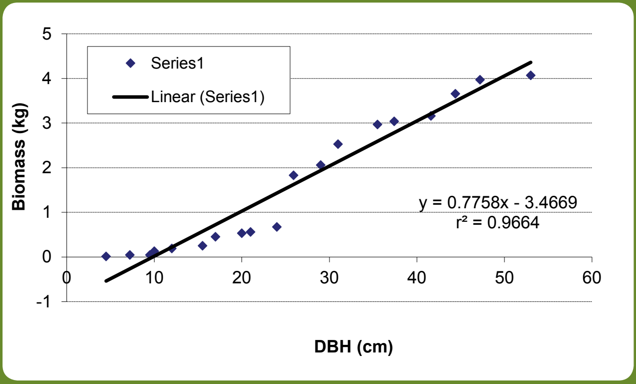


Figure 13: **Linear relationship between tree DBH and oven dry lateral root components**

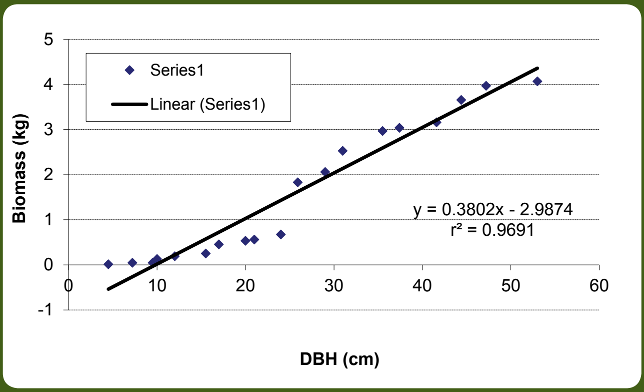


Figure 14: **Linear relationship between tree DBH and oven dry fine root components**

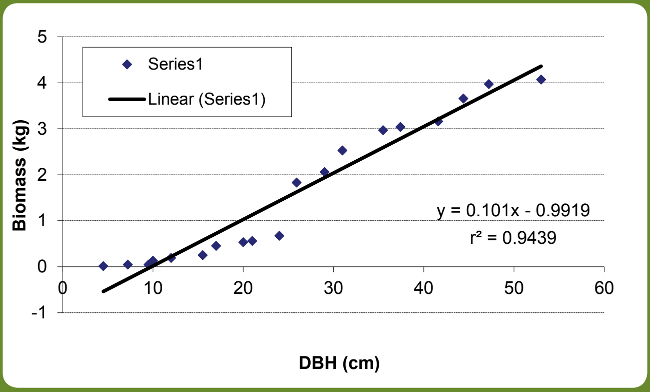


Table 10: **Summary output of stump root components**

Estimate	SE	Residual SE	Multiple r-squared	Adjusted r-squared	t-value	f-statistic	DF	Pr>[t]	P_value
a=-3.4669	1.025	2.166	0.9664	0.9644	-3.38	488.4 on 1	17	0.0035***	< 5.800e^{-1}4
b=0.7758	0.035								

*** highly significant (at 0.001)

Table 11: **Summary output of lateral root components**

Estimate	SE	Residual SE	Multiple r-squared	Adjusted r-squared	T-value	F-statistic	DF	Pr>[t]	P_value
a=-2.9874	0.481	1.017	0.9691	0.9673	-6.205	532.6 on 1	17	9.59e^{-1}4***	< 2.849e^{-1}4
b=0.3802	0.016								

*** highly significant (at 0.001)

Table 12: **Summary output of fine root components**

Estimate	SE	Residual SE	Multiple r-squared	Adjusted r-squared	T-value	F-statistic	DF	Pr>[t]	P_value
a=-0.9919	0.174	1.017	0.3683	0.9673	-5.687	286.3 on 1	17	2.67e-05***	< 4.518e^{-1}2
b=0.101	0.005								

*** highly significant (at 0.001)

It can also be concluded that the wood specific density of *P. tomentosa* is more than one-third of that of the heaviest (960 kg m^{-3}) wood specific density of the *Acacia catechu* (khayar) tree species of Nepal. The wood specific density varies with the species, age, tree composition, site factors, and other many parameters. The wood specific density of the same tree species (*P. tomentosa*) planted in Kargi District of Corum in the northern part of Turkey expressed a wide range of wood specific densities ranging from 272 gm cc^{-1} to 317 gm cc^{-1} (Akyildiz and Kol 2010). The list of the air dried specific wood densities of *P. tomentosa* are presented in Annexes I, II, III, IV, and V.

Table 13: **Specific wood density for *P. tomentosa***

Species	DBH (cm)	Net volume (cc)	Sample dry weight (gm)	Mean specific wood density (gm cc^{-1})
	7.20	3,452.5	755	0.219
	9.50	2,349.6	595	0.253
	10.00	3,260.7	1,065	0.327
	12.00	3,356.6	865	0.258
	15.50	2,685.3	678.2	0.253
	17.00	863.1	241.8	0.280
	20.00	863.1	214.2	0.248
P. tomentosa	21.00	479.5	142.5	0.297
	24.00	575.4	115.6	0.201
	25.90	671.3	154.2	0.230
	29.00	1,438.6	420	0.292
	31.00	767.2	240	0.313
	41.60	3,356.6	1,055	0.314
	47.20	1,630.4	543.8	0.334
	53.00	3,260.7	685	0.210
Mean specific wood density				0.268

Above and below ground tree biomass

Based on analysis from the R-core development software, the highest spread of above ground tree biomass was in Plot 1, while lower spreads of biomass were in Plot 2. Figure 15 shows that there were no outliers in either plot. The median and minimum values of tree biomass showed a uniform pattern in both the plots, indicating that the minimum biomass does not vary significantly.

Table 14 provides a summary of the statistics for total tree biomass (above and below ground) derived from the two plots. The standard deviation was highest (109.06) in Plot 1 and lowest (47.41) in Plot 2. Similarly, the half width of confidence interval at 95% was 128.33 and 79.93 for Plot 1 and Plot 2, respectively. The standard error in both of the plots was within acceptable limits, which is generally up to 25 in forestry sampling.

Figure 15: **Box and whisker plot of tree biomass in Plot 1 and Plot 2**

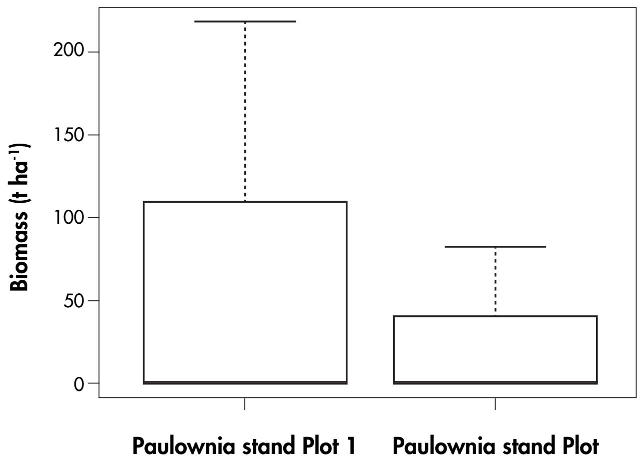


Table 14: **The summary statistics of above and below ground trees biomass**

Plot	Total tree biomass (t ha^{-1})	Standard deviation of above ground biomass	Standard error	95% confidence interval
Plot 1	218.12	109.06	10.20	128.33
Plot 2	82.72	47.41	10.63	79.93

Tree biomass, carbon stock, and carbon dioxide equivalent

The total above and below ground tree biomass for the *P. tomentosa* stand in Plot 1 was 218.12 t ha^{-1} and in Plot 2 was 82.72 t ha^{-1}. The total above and below ground carbon stock in Plot 1, was estimated to be 102.52 tC ha^{-1}, of which about 66.67% was contributed by the stem, 19.31% by branches, 1.49% by twigs, 2.90% by leaves, 6.23% by the stump root, 2.73% by lateral roots, and 0.68% by fine roots. The total above and below ground carbon stock in Plot 2 was estimated to be 38.88 tC ha^{-1}, of which about 66.47% was contributed by the stem, 18.96% by branches, 1.50% by twigs, 2.83% by leaves, 6.81% by the stump root, 2.78% by lateral roots, and 0.66% by fine roots. Based on Table 15, the contribution of the above ground tree components (stem, branches, twigs, and leaves) in Plot 1 was found to be to 90.36%, whereas the contribution of below ground components (stump root, lateral roots, and fine roots) was only 9.64%. Similarly the contribution of the above ground tree components (stem, branches, twigs, and leaves) in Plot 2, was 89.75%, whereas the contribution of below ground components (stump root, lateral roots, and fine roots) was only 10.25%. The total carbon dioxide equivalent in tonnes (tCO_2e) in Plot 1 was 376.24 tCO_2e ha^{-1} and in Plot 2 was 142.68 tCO_2e ha^{-1}.

Table 15: **Component-wise tree biomass and carbon stock of *P. tomentosa* in two experimental plots**

Tree component	Component-wise biomass in two plots ($t\ ha^{-1}$)		Component-wise carbon stock ($tC\ ha^{-1}$) and carbon dioxide ($tCO_2e\ ha^{-1}$) in parenthesis in two plots		Contribution by components to carbon stock in two plots (%)	
	Plot 1	Plot 2	Plot 1	Plot 2	Plot 1	Plot 2
Stem	145.41	54.98	68.34 (250.82)	25.84 (94.84)	66.67	66.47
Branches	42.11	15.68	19.79 (72.64)	7.37 (27.05)	19.31	18.96
Twigs	3.25	1.24	1.53 (5.61)	0.58 (2.14)	1.49	1.50
Leaves	6.33	2.34	2.98 (10.92)	1.10 (4.04)	2.90	2.83
Stump root	13.58	5.63	6.38 (23.42)	2.65 (9.71)	6.23	6.81
Lateral roots	5.96	2.30	2.80 (10.28)	1.08 (3.97)	2.73	2.78
Fine roots	1.48	0.54	0.70 (2.55)	0.25 (0.93)	0.68	0.66
Total	**218.12**	**82.72**	**102.52 (376.24)**	**38.88 (142.68)**	**100.00**	**100.00**

Discussion

P. tomentosa was planted at the ICIMOD Knowledge Park as a research plot to demonstrate and determine its optimum growth performance in the Himalayan mid-hills. Introduced from China 20 years ago, this exotic species did not show an invasive nature. Similarly, with maintained tree spacing of 4 m x 4 m, the *P. tomentosa* showed a growth rate with DBH of 70.8 cm with a maximum tree height of 28.8 m in 20 years. The root sprouts that have grown in between the tree spacing has raised the tree density of younger *P. tomentosa* in both of plots.

The total biomass estimated for 20-year old *P. tomentosa* planted at ICIMOD Knowledge Park is 218.12 t ha^{-1}. Compared to a total biomass estimation of 97.22 t ha^{-1} for a 25-year old *Dalbergia sissoo* mixed plantation in Uttarakhand, India (Joshi 2013) and a total biomass of 89.4 t ha^{-1} for 14.5-year old *Tectona grandis* in a plantation at Sankarnagar in western Nepal (Thapa and Gautam 2005), we estimated a total biomass of 87 to 218.12 t ha^{-1} for 16–21 years old *P. tomentosa* planted in the ICIMOD Knowledge Park. This indicated that the growth of a 25-year old *Dalbergia sissoo* is equivalent to the growth of a 16-year old *P. tomentosa*, which marks this species as a fast-growing species. In addition, the root-shoot ratio of the *P. tomentosa* is 9:1.

Similarly, an assessment of carbon storage by seven-year-old poplar plantations in two different agroforestry systems in two districts of the Terai (viz. Yamunanagar and Saharanpur districts) in India, showed contributions to carbon storage of 27–32 tC ha^{-1} in agroforestry systems and 66–83 tC ha^{-1} in agrisilviculture systems (Rizvi et al. 2010). Another study carried out by (Joshi et al. 2013) on plantations of ten-year-old *Dalbergia sissoo* and eight-year-old Eucalyptus hybrids in the foothills of the Uttarakhand Himalaya estimated the total carbon stock of 21.43 tC ha^{-1} and 29.77 43 tC ha^{-1}, respectively, while in the present study the carbon stock accumulation range varied from 38.88 tC ha^{-1} to 102.52 tC ha^{-1}.

The recent earthquake (25 April 2015, 12 May 2015) and fuel crisis (September-November 2015) has shown that such fast growing species can be popular among rural populations for meeting their timber and energy demand locally. Literatur also sugests that this species has multiple uses including providing fuelwood and fodder, and late winter flowers provide nectar for agriculture.

Conclusion and Recommendations

Among global concerns, climate change has been identified among the most important environmental challenges. Emissions of carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, and perflurocarbons are major contributors to accelerating climate change. International negotiation forums like the United Nations Framework Convention on Climate Change (UNFCCC) have identified the forestry sector as an efficient way to address the reduction of climate change accelerators (like carbon dioxide) through REDD+ initiatives. Carbon stock assessment is an instrumental part of implementing REDD+ approaches.

Carbon stocks around the world are site specific and depend on stand composition, age, soil properties, and the quality and management of the forest. To come up with carbon stock estimates and precise and accurate biomass calculations requires the development of allometric equations. In addition to varying by the age of the forest, carbon sequestration also varies per species as different species behave differently. For example, fast growing species (like *P. tomentosa*, *Eucalyptus* spp., *Dalbergia sissoo*, *Poplar* spp., etc.) sequester more carbon than slow growing species (like oak, sal, etc.). Additionally, habitat variability causes differences in biomass accumulation due to differences in species composition and the respective allometric relationships of the forests; for example, tropical rainforest has the highest potential for carbon sequestration, followed by dry evergreen forest and mixed deciduous forest.

Furthermore, biomass and carbon estimates depend on several environmental and species specific factors. When a species-specific equation does not exist, more general allometric equations or emissions factors provided by IPCC (2006), Chave et al. (2005), and MacDicken (1997) are used. Such general allometric equations are less adequate to predict biomass because, for one thing, they focus on a limited number of tree species with defined tree DBH >12–13 cm, which excludes trees of DBH <12 cm. In addition, they don't represent site-specific geography, and this can result in extrapolated or generalized results of carbon stock. Also, such equations are specially designed to calculate timber volume, which limits the use of other tree components such as branches, foliage, twigs, stump root, lateral roots and, fine roots.

Thus, this study came up with an allometric equation for *P. tomentosa* – $y=14.228x - 120.81$, ($r^2=0.973$) – and component-wise allometric equations, which had previously not existed in Nepal's context. The equation developed by this study can be used for estimating biomass and carbon stocks of Paulownia species grown in regions with similar biotic, climatic, and edaphic factors. Also, the methodology applied by this study and the results can be replicated by other similar studies. Therefore, we recommend that the application of this site-specific allometric equation, developed by this study, should be confined to similar physiographic regions in the middle hills of Nepal representing similar climatic, edaphic, topographic, and biotic factors as in the Godavari forest site.

Nineteen trees were taken as samples from the plots studied; a higher number of tree samples would yield more precise and accurate results. Similar types of destructive sampling techniques can be applied to develop biomass estimation equations in other physiographic zones in Nepal and other parts of the world that do not have an allometric equation for *P. tomentosa*. Such practices would help Nepal to come up with species-specific allometric equations to support national REDD+ strategies. Such allometric equations would allow Nepal to adopt the UNFCCC's Tier 1 approach (ground based measurement with species-specific allometric equations), allowing it to claim the carbon cap and trade benefits involved in REDD+ (UNFCCC 2009).

As it has been proven to be fast-growing species, we recommend that *P. tomentosa* be planted as a mixed crop in agroforestry systems in Nepal. Some of the benefits of *P. tomentosa* plantation include the supply of fodder, fuelwood, and timber. Private landowners can also grow this species on their private land and obtain a return after a short harvesting period. Compared to other species' regeneration and growth rate, this species can rejuvenate degraded land in the short term resulting in the accumulation of biomass and carbon sequestration.

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Annex I: **Tree DBH and height for total number of *P. tomentosa* trees in the study site (Plots 1 and 2)**

SN	Plot	Species	DBH (cm)	Ht (m)
1			54.5	28.1
2			22.5	13.8
3			35.0	24.1
4			52.5	28.6
5			48.3	19.1
6			26	12.5
7			49.5	14
8			57.2	19.1
9			51	26.1
10			21.8	15.5
11			45.5	25.6
12			53.5	26.2
13			53	27
14			30	21.8
15			30	21.5
16			36	25.7
17			35	28.7
18			56.8	28.6
19			29	12.2
20			49.7	18.1
21			18.8	14.8
22			22	23.6
23			33.2	23.7
24			48.5	22.6
25			40.8	21.2
26			23.5	20.8
27	1	*P. tomentosa*	39.2	27.5
28			31.5	13.8
29			70.8	28.8
30			22.4	25.9
31			24.8	16.5
32			19.5	21.5
33			24.2	23.2
34			34.8	21.4
35			27.2	11
36			25	25.6
37			25.2	27.3
38			37.7	22
39			51.5	22.4
40			33.5	18.3
41			29.1	12.7
42			40.6	19.2
43			24.3	21.6
44			51.1	26.4
45			24.4	18.4
46			22	13.8
47			34.5	25.1
48			31.7	22.3
49			40.8	16.7
50			51.8	18.7
51			42.5	20.4
52			26.7	11.2
53			50	18.6
54			31.8	9.4

SN	Plot	Species	DBH (cm)	Ht (m)
1	2	*P. tomentosa*	31	19.3
2			31.5	19.5
3			30.2	20
4			30.3	22.6
5			31.3	18.7
6			11.3	11
7			30.6	23.2
8			10	6.8
9			13.8	14.1
10			14.5	11.5
11			18	12.5
12			11.9	7.2
13			40	18.3
14			15.9	12.9
15			10.8	11
16			30.1	18.3
17			34	22.1
18			39.5	22.1
19			7.8	4.2
20			14	13
21			16.3	13.5
22			16	15
23			25	23.1
24			13	12.5
25			29.5	20
26			37.7	20.2
27			10.9	10.1
28			11.4	11.5
29			24.5	20.1
30			10	8.3
31			33.2	18
32			7.5	6.2
33			8.1	10.2
34			64.6	21
35			67.2	22.6
36			58.2	20.1

Annex II: Number, mean DBH and height of *P. tomentosa* trees in Plot 1 and Plot 2 at ICIMOD Knowledge Park

Plot	No of trees	DBH Class (cm)	Mean DBH (cm)	Mean tree height (m)
Plot 1	NA	<10 cm	NA	NA
	2	10.1–20cm	19.15	18.15
	19	20.1–30 cm	25.26	18.36
	12	30.1–40 cm	34.49	22.35
	10	40.1–50 cm	45.62	23.73
	11	>50 cm	54.88	29.40
Plot 2	5	<10 cm	8.70	7.14
	15	10.1–20cm	13.25	11.39
	2	20.1–30 cm	26.33	21.06
	10	30.1–40 cm	33.80	20.19
	1	40.1–50 cm	40	18.30
	3	>50 cm	64.40	23.20

Annex III: **Tree diameter classes and component-wise mean dry weight of *P. tomentosa* at ICIMOD Knowledge Park**

DBH Class (cm)	Component-wise mean dry weight (kg)						
	Stem	Branches	Twigs	Leaves	Stump root	Lateral roots	Fine roots
<10 cm	8.84	5.16	0.37	0.61	2.83	0.36	0.06
10.1–20cm	67.05	19.29	1.54	1.11	8.54	2.02	0.36
20.1–30 cm	126.59	32.70	2.47	6.12	14.80	7.17	1.28
30.1–40 cm	221.05	54.05	5.02	10.37	23.60	9.75	2.46
40.1–50 cm	319.27	96.63	7.40	14.20	28.76	12.93	3.31
>50 cm	445.3	132.57	9.45	17.93	35.21	15.93	4.07

Annex IV: **Tree diameter classes and component-wise dry weight of *Paulownia tomentosa* at ICIMOD Knowledge Park**

Tree diameter (cm)	Component-wise sample dry weight (kg)						
	Stem	Branches	Twigs	Leaves	Stump root	Lateral roots	Fine roots
7.5	1.87	0.53	0.09	0.32	1.12	0.13	0.02
7.8	9.63	2.05	0.34	0.59	2.83	0.32	0.05
9.5	10.54	7.84	0.42	0.74	3.07	0.39	0.05
10.0	13.30	10.23	0.63	0.79	4.28	0.58	0.13
12.0	43.80	15.21	0.86	0.83	5.63	0.73	0.19
15.5	58.43	17.76	1.53	0.97	5.76	0.93	0.25
17.0	72.64	20.23	1.73	1.07	8.94	2.46	0.45
20.0	93.32	23.94	2.03	1.55	13.82	3.96	0.53
21.0	104.20	26.29	2.80	3.85	10.44	4.82	0.56
24.0	116.70	30.57	2.85	5.85	11.47	6.21	0.68
25.9	135.20	34.37	1.04	6.32	16.82	8.29	1.83
29.0	150.24	39.56	3.21	8.46	20.46	9.37	2.06
31.0	252.70	49.95	5.63	10.83	25.28	9.93	2.53
35.5	236.70	64.17	5.94	11.46	26.81	10.82	2.97
37.4	268.21	69.39	6.02	13.07	27.53	11.06	3.04
41.6	304.50	83.23	7.95	14.89	29.80	11.73	3.16
44.4	356.10	122.80	7.84	15.23	30.39	14.82	3.66
47.2	395.43	126.43	8.78	16.29	31.25	15.43	3.97
53.0	445.30	132.57	9.45	17.93	35.21	15.93	4.07

Annex V: **Air dried specific wood density of *P. tomentosa***

A. **Tree diameter classes and total fresh weight, sample fresh weight, sample dry weight, and total dry weight of stem component of *P. tomentosa***

Tree diameter (cm)	Total fresh weight of stem (kg)	Position-wise sample fresh weight (kg)				Position-wise sample dry weight (kg)				Total dry weight of stem (kg)
		Base	Middle	Top	Sample fresh weight of stem (kg)	Base	Middle	Top	Sample dry weight of stem (kg)	
7.5	3.21	0.50	0.30	0.30	1.10	0.12	0.07	0.45	0.64	1.85
7.8	20.60	1.60	1.40	1.00	4.00	0.76	0.58	0.52	1.86	9.58
9.5	24.70	1.50	1.40	1.00	3.90	0.67	0.46	0.52	1.65	10.45
10	26.50	1.70	1.10	0.74	3.54	1.00	0.45	0.33	1.77	13.26
12	70.60	2.50	1.40	1.00	4.90	1.47	0.89	0.68	3.04	43.76
15.5	108.20	2.00	1.80	1.10	4.90	1.32	0.78	0.54	2.65	58.43
17	114.60	2.00	1.40	1.00	4.40	1.56	0.86	0.37	2.79	72.67
20	182.60	1.60	1.00	0.50	3.10	0.74	0.52	0.32	1.58	93.24
21	264.20	1.80	1.10	0.56	3.46	0.73	0.42	0.21	1.36	104.15
24	270.48	2.50	1.10	0.74	4.34	1.11	0.52	0.25	1.88	116.85
25.9	301.80	1.50	1.50	1.00	4.00	0.78	0.65	0.35	1.79	135.13
29	375.20	1.10	0.67	0.50	2.27	0.57	0.22	0.12	0.91	150.08
31	486.50	2.00	1.40	0.87	4.27	1.49	0.43	0.30	2.22	252.48
35.5	495.60	2.40	1.20	1.00	4.60	0.85	0.68	0.67	2.20	237.13
37.4	532.40	1.70	1.30	1.10	4.10	0.98	0.66	0.43	2.07	268.28
41.6	873.20	1.80	1.50	1.30	4.60	0.58	0.65	0.37	1.60	304.29
44.4	1082.40	1.50	1.20	1.00	3.70	0.53	0.43	0.25	1.22	356.61
47.2	1452.25	2.50	1.50	1.00	5.00	0.49	0.42	0.45	1.36	395.59
53	2002.22	2.50	1.00	1.00	4.50	0.42	0.36	0.23	1.00	445.38

B. Tree diameter classes and total fresh weight, sample fresh weight, sample dry weight, and total dry weight of branches component of *P. tomentosa*

Tree diameter (cm)	Total fresh weight of branches (kg)	Position-wise sample fresh weight (kg)				Position-wise sample dry weight (kg)				Total dry weight of branches (kg)
		Base	Middle	Top	Sample fresh weight of branches (kg)	Base	Middle	Top	Sample dry weight of branches (kg)	
7.5	1.67	0.10	0.10	0.10	0.30	0.04	0.03	0.02	0.10	0.54
7.8	5.95	1.00	0.50	0.30	1.80	0.32	0.22	0.08	0.62	2.05
9.5	23.19	1.50	1.40	1.00	3.90	0.69	0.34	0.29	1.32	7.83
10	27.30	1.50	1.10	0.50	3.10	0.44	0.43	0.30	1.17	10.27
12	32.30	1.50	1.00	1.00	3.50	0.79	0.44	0.42	1.64	15.15
15.5	38.08	1.40	0.50	0.50	2.40	0.65	0.25	0.22	1.12	17.72
17	45.22	2.00	1.40	1.00	4.40	1.02	0.56	0.37	1.95	20.04
20	55.12	1.60	1.00	0.50	3.10	0.63	0.42	0.30	1.35	23.91
21	52.50	1.50	1.00	0.50	3.00	0.88	0.38	0.25	1.50	26.25
24	66.50	1.50	1.50	1.00	4.00	1.17	0.42	0.25	1.84	30.54
25.9	74.63	1.50	1.50	1.00	4.00	0.79	0.67	0.38	1.84	34.33
29	82.71	1.10	0.50	0.50	2.10	0.67	0.21	0.12	1.01	39.58
31	88.35	2.00	1.00	0.50	3.50	1.25	0.42	0.31	1.98	49.91
35.5	110.61	2.00	1.00	0.50	3.50	1.04	0.67	0.32	2.03	64.19
37.4	118.60	1.50	1.00	1.00	3.50	0.95	0.42	0.67	2.05	69.33
41.6	222.10	1.50	1.50	1.30	4.30	0.58	0.65	0.38	1.61	83.16
44.4	261.23	1.50	1.00	1.00	3.50	0.65	0.53	0.45	1.64	122.40
47.2	464.20	2.50	1.50	1.00	5.00	0.49	0.42	0.45	1.36	126.45
53	596.10	2.50	1.00	1.00	4.50	0.42	0.36	0.23	1.00	132.60

C. Tree diameter classes and total fresh weight, sample fresh weight, sample dry weight, and total dry weight of twigs component of *P. tomentosa*

Tree diameter (cm)	Total fresh weight of twigs (kg)	Sample fresh weight of twigs kg)	Sample dry weight of twigs (kg)	Total dry weight of twigs (kg)
7.5	0.36	0.10	0.02	0.09
7.8	0.57	0.10	0.06	0.34
9.5	0.78	0.10	0.06	0.43
10	0.99	0.10	0.06	0.63
12	1.81	0.10	0.05	0.87
15.5	2.42	0.50	0.32	1.54
17	2.78	0.50	0.31	1.73
20	3.95	0.50	0.26	2.03
21	4.54	0.50	0.31	2.79
24	4.85	0.50	0.29	2.80
25.9	4.91	0.50	0.11	1.04
29	5.22	0.50	0.31	3.26
31	7.62	0.50	0.37	5.64
35.5	7.82	0.50	0.38	5.91
37.4	8.15	0.50	0.37	6.05
41.6	10.30	0.50	0.39	7.95
44.4	12.67	0.50	0.31	7.84
47.2	14.65	0.50	0.30	8.78
53	14.97	0.50	0.32	9.45

D. Tree diameter classes and total fresh weight, sample fresh weight, sample dry weight, and total dry weight of leaves component of *P. tomentosa*

Tree diameter (cm)	Total fresh weight of leaves (kg)	Sample fresh weight of leaves (kg)	Sample dry weight of leaves (kg)	Total dry weight of leaves (kg)
7.5	1.62	0.10	0.02	0.32
7.8	2.46	0.10	0.02	0.59
9.5	2.98	0.10	0.03	0.75
10	3.06	0.10	0.03	0.80
12	3.46	0.10	0.02	0.83
15.5	4.86	0.10	0.02	0.97
17	5.12	0.10	0.02	1.08
20	6.52	0.10	0.02	1.56
21	11.45	0.10	0.03	3.89
24	20.32	0.10	0.03	5.89
25.9	25.29	0.10	0.03	6.32
29	27.31	0.10	0.03	8.47
31	29.30	0.10	0.04	10.84
35.5	33.72	0.10	0.03	11.46
37.4	35.38	0.10	0.04	13.09
41.6	38.30	0.10	0.04	14.94
44.4	40.20	0.10	0.04	15.28
47.2	44.08	0.10	0.04	16.31
53	47.22	0.10	0.04	17.94

E. Tree diameter classes and total fresh weight, sample fresh weight, sample dry weight, and total dry weight of stump root component of *P. tomentosa*

Tree diameter (cm)	Total fresh weight of stump root (kg)	Position-wise sample fresh weight (kg)				Position-wise sample dry weight (kg)				Total dry weight of stump root (kg)
		Base	Middle	Top	Sample fresh weight of stump root (kg)	Base	Middle	Top	Sample dry weight of stump root (kg)	
7.5	3.68	0.10	0.10	0.10	0.30	0.04	0.03	0.02	0.09	1.12
7.8	8.37	1.00	0.50	0.30	1.80	0.31	0.22	0.08	0.61	2.84
9.5	9.28	1.50	1.40	1.00	3.90	0.68	0.33	0.28	1.29	3.08
10	11.35	1.50	1.10	0.50	3.10	0.44	0.43	0.30	1.17	4.27
12	14.58	1.00	1.00	1.00	3.00	0.45	0.33	0.39	1.16	5.64
15.5	23.68	1.50	1.50	1.00	4.00	0.51	0.25	0.22	0.97	5.76
17	25.67	1.50	1.50	1.00	4.00	0.65	0.46	0.28	1.39	8.94
20	31.90	1.60	1.00	0.50	3.10	0.63	0.42	0.30	1.35	13.84
21	40.98	1.60	1.00	1.00	3.60	0.38	0.32	0.22	0.92	10.43
24	47.80	2.00	1.50	1.00	4.50	0.51	0.37	0.21	1.08	11.45
25.9	50.85	1.60	1.00	1.00	3.60	0.52	0.36	0.32	1.19	16.81
29	60.97	1.50	1.00	0.50	3.00	0.67	0.21	0.12	1.01	20.42
31	64.10	1.00	1.00	1.00	3.00	0.43	0.45	0.30	1.18	25.30
35.5	69.67	1.50	1.00	1.00	3.50	0.63	0.42	0.30	1.35	26.77
37.4	70.32	1.50	1.00	1.00	3.50	0.59	0.47	0.32	1.37	27.57
41.6	74.10	1.50	1.50	1.00	4.00	0.58	0.65	0.38	1.61	29.83
44.4	77.82	1.50	1.00	1.00	3.50	0.57	0.43	0.37	1.37	30.42
47.2	83.98	1.00	1.50	1.00	3.50	0.48	0.42	0.40	1.30	31.26
53	95.47	1.50	1.00	1.00	3.50	0.42	0.36	0.52	1.29	35.21

F. Tree diameter classes and total fresh weight, sample fresh weight, sample dry weight, and total dry weight of lateral roots component of *P. tomentosa*

Tree diameter (cm)	Total fresh weight of lateral roots (kg)	Sample fresh weight of lateral roots (kg)	Sample dry weight of lateral roots (kg)	Total dry weight of lateral roots (kg)
7.5	0.65	0.10	0.02	0.14
7.8	1.12	0.10	0.03	0.32
9.5	1.55	0.10	0.03	0.39
10	2.16	0.10	0.03	0.58
12	2.62	0.10	0.03	0.73
15.5	3.48	0.10	0.03	0.94
17	5.98	0.10	0.04	2.45
20	8.84	0.10	0.05	3.98
21	9.95	0.10	0.05	4.78
24	12.87	0.10	0.05	6.18
25.9	15.10	0.10	0.06	8.31
29	22.60	0.10	0.04	9.27
31	26.89	0.10	0.04	9.95
35.5	29.31	0.10	0.04	10.84
37.4	29.94	0.10	0.04	11.06
41.6	30.20	0.10	0.04	11.73
44.4	30.81	0.10	0.05	14.82
47.2	33.50	0.10	0.05	15.43
53	33.84	0.10	0.05	15.93

G. Tree diameter classes and total fresh weight, sample fresh weight, sample dry weight, and total dry weight of fine roots component of *P. tomentosa*

Tree diameter (cm)	Total fresh weight of fine roots (kg)	Sample fresh weight of fine roots (kg)	Sample dry weight of fine roots (kg)	Total dry weight of fine roots (kg)
7.5	0.07	0.07	0.02	0.02
7.8	0.08	0.08	0.05	0.05
9.5	0.10	0.10	0.05	0.05
10	0.36	0.10	0.04	0.13
12	0.41	0.10	0.05	0.19
15.5	0.75	0.10	0.03	0.25
17	0.98	0.10	0.05	0.44
20	1.15	0.10	0.05	0.53
21	1.15	0.10	0.05	0.56
24	1.39	0.10	0.05	0.68
25.9	3.87	0.10	0.05	1.83
29	4.43	0.10	0.05	2.06
31	4.66	0.50	0.27	2.53
35.5	4.96	0.50	0.30	2.97
37.4	5.21	0.50	0.29	3.04
41.6	5.47	0.50	0.29	3.16
44.4	5.98	0.50	0.30	3.66
47.2	6.83	0.50	0.29	3.97
53	6.88	0.50	0.30	4.07

Annex VI: **Data collection sheets**

Data Collection Sheet for Allometric Equation Development

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 center:

1. Background information

Place Name: ______
Forest Name: ______
Block number: ______

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

2. Plot informantion

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

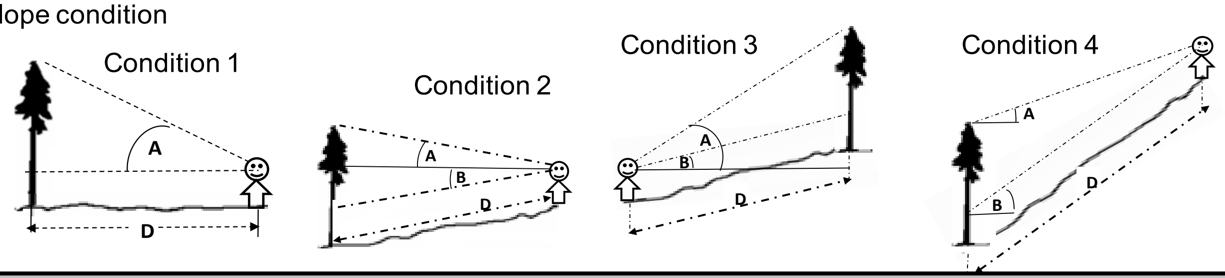
	Please circle one
Forest type:	natural / plantation
Aspect:	N, S, E, W, NE, NW, SE, SW, Flat
Soil type:	clayey, loam, sandy, boulder
fire:	Yes / No
fodder collection:	Yes / No
grazing:	Yes / No
fuelwood collection:	Yes / No
timber harvesting:	Yes / No
encroachment:	Yes / No
wildlife:	Yes / No
soil erosion: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

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

Any additional information

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		Distance to the tree (m)	Slope condition (see figure above)	Tree height (m)	Remarks
			top (A)	base (B)	(D)			
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**

Annex VII: List of instruments and equipment and their purpose

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 to ensure that it is measured.
Leaf litter and herb/grass collection		
	Plastic bags	White plastic bags to collect samples and big plastic bags to collect and weigh stem, branch wood discs, and stump roots
	Cloth bags	As plastic bags may tear, samples of leaves, twigs lateral roots, and fine roots should be collected in cloth bags.
	Knife or sickle	For cutting leaves and twigs
	Weighing machine	For weighing samples fresh weight
	Scissors	For cutting 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.

Annex VIII: **Analytical data record of oven dry mass of woody sample trees**

Name of Laboratory :

Date of data report:

Name of persons in charge:

ID	**Sample tree name and DBH class(cm)**	**Sample part**	**Total fresh weight(Kg)**	**Sample fresh weight(Kg)**	**Sample dry weight(Kg)**	**Total dry weight(Kg)**
1		Bole				
		Branch				
		Twigs				
		Leaves				
		Stump root				
		Lateral root				
		Fine root				
2		Bole				
		Branch				
		Twigs				
		Leaves				
		Stump root				
		Lateral root				
		Fine root				
3		Bole				
		Branch				
		Twigs				
		Leaves				
		Stump root				etc....

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