WORKING PAPER

Forest carbon stock assessment in selected red panda habitats in Ilam and Panchthar districts, Nepal

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Forest carbon stock assessment in selected red panda habitats in Ilam and Panchthar districts, Nepal

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Abbreviations and acronyms

AGB	Above-ground biomass
AGSB	Above-ground sapling biomass
AGTB	Above-ground tree biomass
BGB	Below-ground biomass
DBH	Diameter at breast height
FAO	Food and Agriculture Organization
FCPF	Forest Carbon Partnership Facility
GHG	Greenhouse gas
GIS	Geographical Information system
GPS	Global Positioning System
Ha	Hectare
HKH	Hindu Kush Himalaya
ICIMOD	International Centre for Integrated Mountain Development
IPCC	Intergovernmental Panel on Climate Change
KL	Kanchenjunga Landscape
MoFE	Ministry of Forests and Environment
MoFALD	Ministry of Federal Affairs and Local Development
MRV	Measurement, reporting, and verification
NDC	Nationally determined contribution
PIT Corridor	Panchthar-Ilam-Taplejung Corridor
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RPN	Red Panda Network
RS	Remote sensing
SOC	Soil Organic Carbon
UNFCCC	United Nations Framework Convention on Climate Changes

Acknowledgements

This report is based on a study conducted during the months of June–July 2018 in the red panda habitats of eastern Nepal. The study was jointly conducted by a team from the Red Panda Network (RPN) and the International Centre for Integrated Mountain Development (ICIMOD). This work would not have been possible without the support and supervision of Ang Phuri Sherpa, Country Director of the RPN. Sincere gratitude also goes to the RPN team of Pema Sherpa, Munmum Lama, Sanjaya Tamang, Sony Lama, and Deependra Sunar, as well as Sunayana Basnet of ICIMOD for helping in the collection of data across the study plots. We also appreciate the contribution of the Agricultural Technological Center lab for testing the soil carbon content.

A section of this study included training in forest carbon measurement practices for the local population involved in the field data collection. This training, along with the fieldwork, added to the capacity building of the local resource persons. We would like to thank all these resource persons for their active participation in the analysis, and are hoping that this will also be useful for future projects.

Executive summary

This report has been prepared under the Community-based Red Panda Conservation in Eastern Nepal project in collaboration with ICIMOD and the RPN. Scientific data collection methods for monitoring forest carbon were developed and applied to the three study sites – Gorkhe, Dobate, and Gorwalebhanjyag – that fall in the Panchthar-Ilam-Taplejung (PIT) Corridor.

The PIT Corridor within the Kanchenjunga Landscape, Nepal (KL-Nepal) covers approximately 2,700 ha. The percentage of forest cover in Ilam, Panchthar, and Taplejung districts are 56, 48, and 43 respectively. The PIT Corridor spans important global biodiversity spots of the Kanchenjunga Conservation Area, the Barsey Rhododendron Garden, and the Singhalila National Park. The various fauna found in this region include snow leopard, clouded leopard, and Himalayan black bear. The area also includes over 605 sq. km of red panda (*Ailurus fulgens*) habitat that supports approximately 25% of the country's total population. Red panda is a flagship species and a sensitive biodiversity indicator of ecological health in the eastern part of Nepal. However, red pandas have been increasingly threatened by habitat loss and forest fragmentation.

The study conducted forest carbon assessments in 42 sample plots, with one hectare as the sampling plot size. Data on above-ground carbon pools like above-ground tree, sapling, and seedling were collected, along with soil organic data, to measure the total carbon stock. The result of the data analysis shows chances of enhancement and possibilities of carbon sequestration in the future. The restoration of the forest ecosystems, especially the bamboo plantation in red panda habitat, will not only conserve the red pandas, but can also benefit other species in this region. It was also found that other ecosystem services will improve through the practice of sustainable management of forest and the inclusion of community members in the endeavour.

KEY MESSAGES

Forest carbon content is adversely affected by climate change. Increasing human activities and disturbances lead to deforestation and degradation of forest cover, therefore fragmenting red panda habitat.

SECTION I

Introduction

Forest degradation has critically affected the habitat of the endangered red panda in the eastern Himalaya. There is a need for greater habitat protection and sustainable forest management.

1.1 Forest and biomass

Forest plays a vital role in the global carbon cycle by either storing carbon or by operating as a sink to the carbon dioxide emitted through anthropogenic activities (Houghton et al. 2009; Le Quéré et al. 2015; Yu and Saatchi 2016). Forest ecosystems are not just important to the lives and livelihood of humans, they are also needed to support global biodiversity (Escobedo et al. 2011; Karki et al. 2016; Raich et al. 2014). They are the most widely scattered terrestrial vegetation type. But issues like deforestation and forest degradation have been affecting this vegetation and its capabilities. Conversion of forest land to other land cover in developing countries has had a significant impact on the accumulation of greenhouse gases in the atmosphere (Thapa et al. 2014 b). The knowledge of the patterns and processes of deforestation and forest degradation is essential to plan management approaches in order to protect and provide long-term sustainability (Qamer et al. 2016).

Carbon sequestration, or the carbon stored in forests, exists in the form of the biomass of tree/forest (Vashum et al. 2012). In the context of climate change, monitoring forest biomass has become a challenging task (Avtar et al. 2014). The estimation of biomass content in an area includes the assessment of both above- and below-ground materials. It has been found that deforestation and forest degradation activities affect above-ground biomass (AGB) more than the below-ground biomass (BGB) content (Maina et al. 2017), thereby rendering the calculation of AGB significant. Various studies suggest the importance of information on the AGB stock. Information about forest stand structure and quantification of AGB are of great importance to assess forest ecosystem productivity, determine carbon budget, and support studies of the role of forests in the global carbon cycle (Attarchi et al. 2014). In the forestry field, AGB is considered one of the six pools that's required for the preparation of a forest resource inventory and to estimate the greenhouse gas sink (Maina et al., 2017).

1.2 REDD+ and remote sensing

Owing to the pernicious effects of deforestation and forest degradation, an intercontinental environmental movement and international governance of forests came into play through treaties and pacts like the United Nations Framework Convention on Climate Change (UNFCCC) with its Kyoto Protocol. Under the UNFCCC discussion, a mechanism to conserve and monitor forests was debated which led to the formulation of REDD+ (Reduction of Emissions from Deforestation and Forest Degradation) which promotes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks mainly in the developing countries. The developed countries reward the developing ones on the basis of their performance in forest conservation (Roessing Neto 2015). The initial goal of REDD+ was to address the problem of climate change by reducing deforestation and forest degradation at the national and subnational levels. Now, due to increasing demand from local communities and the need to tackle on-ground realities, REDD+ addresses issues on a global scale (Myers et al. 2018). Hence, the influence of REDD+ will grow over the years to come.

The effects of climate change mitigation through REDD+ over a large geographical area depends on the mapping and analysing of forest carbon stock and emission (Asner et al. 2010). This is done through the use of remote sensing (RS) and Geographic Information System (GIS) technology. This technology provides practical and cost-effective solutions for the developing countries to map and maintain REDD+ monitoring systems (De Sy et al. 2012). The accurate estimation of forest biomass over a wider area is becoming more and more important to conduct research on the carbon cycle (Ni et al. 2014). The progress in RS and ground-based technologies have allowed for monitoring forests in high spatial, temporal, and thematic detail (Devries et al. 2016). An efficient RS tool is helpful in setting up effective monitoring, reporting and verification systems (MRVs), a vital parameter for REDD+ success (Murthy et al. 2017).

1.3 Nepal and red panda

The forest cover of Nepal is around 36 million ha, which is 25.4% of the country's total land area (FAO 2015). The annual deforestation rate, from 1990 to 2000, was at 1.9% (Butler 2014). Recent studies indicate that even though deforestation is continuing, afforestation and restoration practices have reduced the annual net loss (FAO 2005). In fact, it is forest degradation that is the more pressing issue than deforestation (Acharya et al. 2011). Natural disturbances like fire, diseases, unsustainable exploitation, illegal logging, and overgrazing are some of the reasons for forest degradation. Proper management/policy measures can effectively reduce these disturbances. It was in 2008 that Nepal started implementing its REDD+ project with the Forest Carbon Partnership Facility – FCPF (REDD in Nepal 2019). The country has been actively committed to REDD+ readiness and implementation processes to reduce emissions by limiting deforestation and forest degradation. The Nationally Determined Contribution (NDC) goals submitted to the UNFCCC discusses strategies to reduce biomass dependency; these include the use of alternative energy, conserving the existing forest cover, and enhancing carbon sequestration through sustainable forest management (MoFE 2018a). Nepal's annual emissions and removals due to deforestation and afforestation are 929,325 tCO_2e /year and -151,077 tCO_2e/year respectively. (MoFE 2018b).

The dense, isolated forests of Nepal are the prime habitat of the red panda (Panthi et al. 2019). The threats to this animal have been determined to be habitat loss due to degradation and destruction of forests (Thapa et al. 2014 a). Bista et al. (2019) indicate that the red panda has a strong inclination towards areas abundant in bamboo and a high tree canopy; they like to live in a place where there's a water source and which is away from human settlements. But, like other wildlife species, the red panda's population is facing a threat from human interference (Dendup 2016). The destruction of forests has had several effects on the red pandas – such as fragmentation of their population and the despoiling of their feeding habitat (Jnawali et al. 2012; Acharya et al. 2018).

1.4 Objectives

The overall objective of the study was to monitor the forests in the PIT Corridor and prepare a report for a forest carbon study. The specific objectives were to:

- Determine the above-ground biomass and forest carbon in the three study sites under Ilam and Panchthar districts.
- Collect field data for a baseline report.
- Form an initial guideline for future forest carbon stock estimations.

The rationale of this study was to collect data and information on forest biomass and carbon stock.

KEY MESSAGES

The study sites – the Dobate, Gorkhe, and Gorwalebhanjyag forests – cover an area of 27.07 sq. km. An annual deforestation rate of 3.2% is recorded in these areas, which is higher than national average.

SECTION II

Overview of the research site

Ilam and Panchthar contain prime habitats of the red panda. The vegetation cover of the study sites can be divided into two broad categories: lower tropical zone forest and upper tropical zone forest.

2.1 Site description

The study sites were located mainly in the mountainous district of Ilam in Province 1. (Ilam is also known as the "Queen of Hills".). The altitude ranges from 1,270–3,636 masl and most of the district's area falls in the Mahabharata range and some in Siwalik. The entire district covers a total area of 1,703 sq. km, but the specific sites for our study were three forests – Dobate, Gorkhe, and Gorwalebhanjyag – with a combined area of 27.07 sq. km (Figure 1). These sites were chosen because they are the prime habitats of the red panda and a baseline study would be useful for future reference. The sites fall in the PIT Corridor, and even covers the Kanchenjunga Landscape, thereby making it an important part of a transboundary landscape within the Hindu-Kush Himalaya (HKH) region. A study by the RPN in 2011 had found that the annual deforestation rate in the PIT Corridor is approximately 3.2%, well above the national average of 1.3% (Lippe 2016).

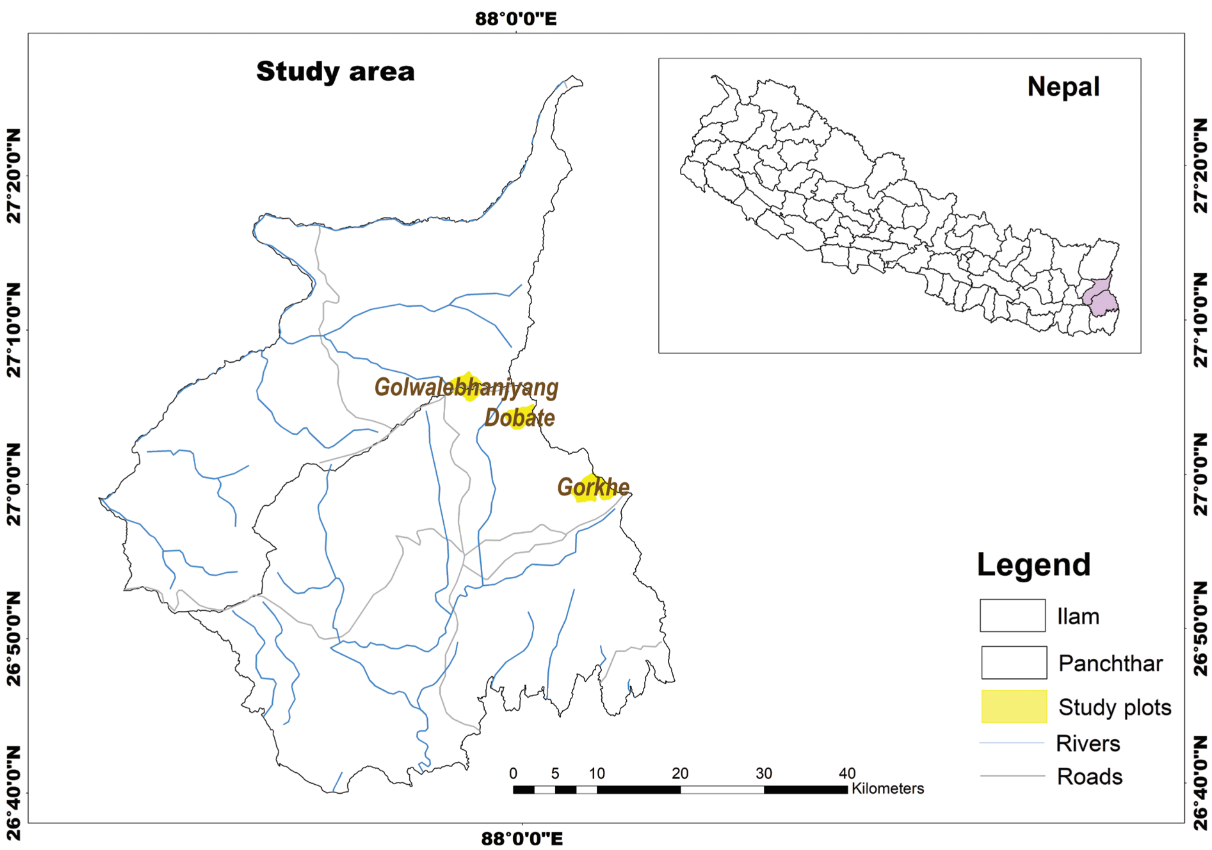
2.2 Climate

The sites are located in warm and temperate climes. The average temperature is around 18.80°C, with a maximum average of 22.50°C in August and a minimum average of 12.40°C in January. December is the driest month, with precipitation as low as 12 mm on an average, and July the wettest, with 74 mm precipitation (Climate-data.org 2020).

2.3 Forest types and soil

The vegetation cover can be divided into two broad categories: lower tropical zone forest and upper tropical zone forest. The vegetation type dominant in the lower zone is *Shorea robusta* (sal), *Acacia catechu* (khair), and *Dalbergia sissoo* (sisau). The dominant vegetation in the upper zone is *Terminalia alata* (saj), *Schima wallichii* (chilaune), and sal. But these flora are now under threat because of deforestation and forest degradation, and are in urgent need of adequate conservation and sustainable management practices (MoFALD 2017). The soil type prominent in the area is sandy clay loam (chimte) (MoFALD 2017).

FIGURE 1 STUDY SITE AT ILAM DISTRICT, NEPAL



KEY MESSAGES

To cover the heterogeneity of the forest cover, 37 plots were randomly selected and 5 systematically placed. Each of the 42 plots were divided into 25 sub plots and slope corrections were applied for the use of remote sensing data.

SECTION III

Methodology

Information on above-ground tree and sapling biomass, and soil organic carbon was collected from 42 plots across the sites.

3.1 Forest carbon estimation

In 2003, the Intergovernmental Panel on Climate Change identified five major carbon pools in the terrestrial ecosystem involving biomass: above-ground biomass, below-ground biomass, litter, wood debris, and soil organic matter. Among all of these, above-ground biomass constitutes a major portion of carbon; hence, estimating its loss due to deforestation is a crucial component of data for management purposes (Vashum et al. 2012). Forest biomass stock measurements and observations of these over time are essential for the development of a reference scenario and a baseline survey (Bhattarai et al. 2015). Assessing and mapping forest carbon generally involves a combination of two or more methods like remote sensing, field calculations, modelling, and statistical measures (Birdsey et al. 2013).

This study involved field data collection which could serve as the baseline information for the estimation of carbon stock changes for further studies. The sampling plots were marked using GPS (Global Positioning System) on field and were mapped using the shapefile and XY coordinate feature in the ArcGIS software. The data from the field was entered using Microsoft Excel.

3.2 Sampling

The concern of uncertainties in field data collection is always there, with the variation in plot size being one of the factors. Currently, there might not be standard plot-size guidelines for a combination of field data with RS technology. But various studies have been conducted with a difference in plot size and the final estimation is generally on per hectare basis which equals a square plot of satellite imagery pixel (100*100 m) (Omar et al. 2013).

Hence, hectare plots were selected for the field survey based on a standardized method (Thapa et al. 2015). A total of 42 plots were selected, out of which 37 were randomly generated and 5 systematically placed to cover the heterogeneity of the forest cover. Each of the plots was further subdivided into a 5*5 grid, creating 25 subplots. Out of these 25 subplots, 5 plots (4 from each corner and one at the centre) with 20 m spacing was used (Figure 2). Dobate had 14 plots, Gorkhe 16 and Gorwalebhanjyag 12.

3.3 Measurement of forest carbon pools

The estimation of above-ground tree biomass, above-ground sapling and soil organic content was done. The details of each are mentioned below.

3.4 Above-ground tree biomass

All trees equal to or above 5 cm dbh (diameter at breast height) within a plot (20*20 m) were measured for diameter and height using a dbh tape and clinometers respectively (Annex 6). The allometric equation (Chave et al. 2005) mentioned below (Equation 1) was used for the AGTB (above-ground tree biomass) calculation which includes the parameters on dbh, height, and wood density.

*AGTB = 0.0509*p D²H* (Equation 1)

$$AGTB = 0.0509 * p D^2 H \quad \text{(Equation 1)}$$

Where,
AGTB = above-ground tree biomass
P = wood-specific gravity (g/cm^3)
D = tree dbh (cm)
H = tree height (m)

3.5 Above-ground sapling biomass

A sapling with a diameter between 1 and 5 cm was measured. The AGSB was analysed (within 10*10 m) using a site and species-species national allometric model (Equation 2), which had been developed jointly by the Department of Forest Research and Survey, the Tree Improvement and Silviculture Component and the Department of Forest, Nepal (Tamrakar 2000).

$$Log (AGSB) = a + b \log (D) \quad \text{(Equation 2)}$$

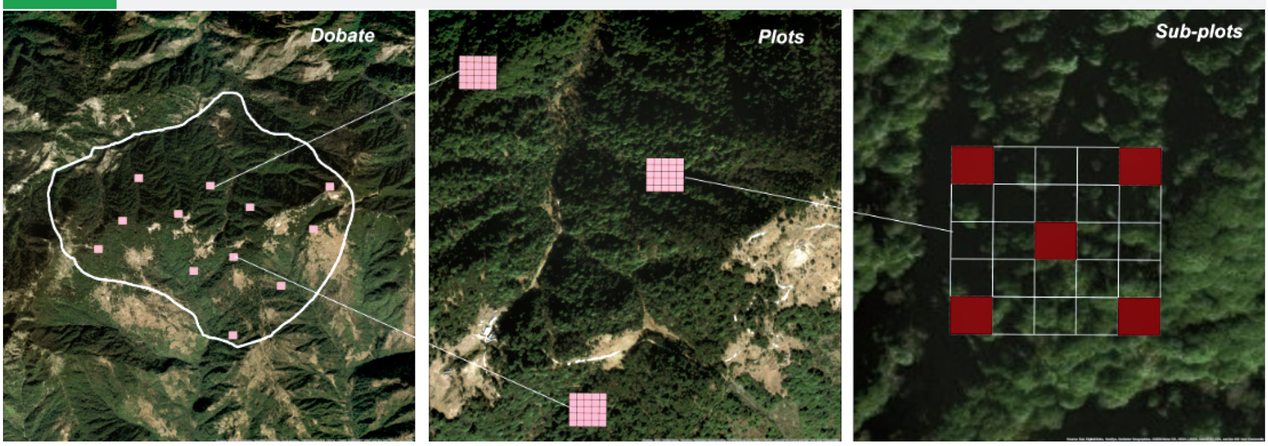
Where,
Log = natural log (dimensionless)
AGSB = above-ground sapling biomass (kg)
A = intercept of allometric relationship for sapling
B = slope of allometric relationship for sapling (dimensionless)
D = sapling dbh (cm)

Within a 3*3 m area of the subplot, the count of seedlings was also recorded. This was done to understand the forest structure and to gain knowledge on the regeneration capacity of the forest cover across the three sites.

3.6 Soil organic carbon

The soil organic carbon (SOC) was calculated by taking soil samples at three 10 cm intervals (0–10 cm, 11–20 cm, and 21–30 cm) with the standard 100 cm3 metal rings. A sieve was used to remove rocks and plant residue. The fresh weight of the sample was collected with 0.1 g precision. From five subplots, only one sample of soil was collected, making it 42 soil samples. The bulk density of each of them was also calculated before being transported to a lab for

FIGURE 2 PLOT AND SUBPLOT LOCATION IN ONE OF THE STUDY SITES



carbon concentration calculation. Lastly, organic carbon was calculated using the following equation (Pearson et al. 2007; Dahal et al. 2012):

$$SOC = p * D * \% C \qquad \text{(Equation 3)}$$

Where,

SOC = soil organic carbon stock per unit area (t ha)

p = soil bulk density (g cm^3)

D = the total depth at which the sample was taken (m)

% C = carbon concentration (%)

3.7 Slope correction

The canopy height of any forest type is a crucial variable for quantifying carbon storage in a terrestrial ecosystem (Shugart et al. 2010; Park et al. 2014). The process of slope correction varies and the one applied for this study was through the use of SRTM DEM. It helped in generating accurate slope degrees in each area using the ArcGIS tools. The GPS points of the plots were used to extract the slope value of each subplot and the following formula (Equation 4) was used to correct the terrain errors.

$$SC = 1/ \cos (a * pi () /180) \qquad \text{(Equation 4)}$$

Where,

SC = slope correction

A = slope degree

PI = pi value (3.14)

3.8 Total forest carbon stock

Each forest carbon pool was summed up to estimate the total forest carbon stock. And the equation used to calculate the total forest carbon stock was (Equation 5):

$$TC (LU) = C (AGTB) + C (AGSB) + SoC \qquad \text{(Equation 5)}$$

Where,

TC (LU) = total carbon stock for a land-use category (tC ha)

C (AGTB)= carbon stock in above-ground tree biomass (tC ha)

C (AGSB)= carbon stock in above-ground sapling biomass (tC ha)

SoC = soil organic carbon (tC ha)

All the pools of the forest biomass were converted into forest carbon by multiplying with a default value of 0.47 for the various ecological forest classes (IPCC 2006).

KEY MESSAGES

As 76% of the plots recorded a carbon stock of over 100 tC/ha, relevant activities to improve the forest quality and its management could be carried out. The rest of the plots will possibly transition from being sparsely forested to densely forested through plantation activities.

SECTION IV

Results and discussions

The plots exhibit high carbon stock and regenerating forest structure, suggesting possibilities for forest cover enhancement and implementation of sustainable forest management practices.

4.1 Dominant tree species in the study sites

Out of the 64 different tree species recorded in the three study sites, we have listed the most commonly distributed species in the 42 plots (Annex 1). The dominant species found were *Rhododendron arboreum* (gurans), *Symplocos sumuntia* (kholmen), and *Rhododendron falconeri* (korlinga) in Dobate, Gorkhe, and Gorwalebhanjyag respectively. The graph (Figure 3) shows the occurrence of five dominant tree species in the three sites.

4.2 Tree count

The tree count comprises all trees with their diameter at a dbh of above 5 cm. A total of 3,966 trees were recorded (Table 1). The details of trees in each plot are listed in Annex 2.

4.3 Diameter range

The total count of trees in the first two ranges, i.e. below 10 and between 10–20 cm, was larger than any other diameter range. Around 1,493 and 1,583 trees were recorded in these two ranges respectively,

TABLE 1 A BRIEF SOCIO-ECONOMIC BACKGROUND OF THE STUDY VILLAGES

Study sites	No. of plots	Total no. of trees
Dobate	14	1,615
Gorkhe	16	1,530
Gorwalebhanjyag	12	821
Total	**42**	**3,966**

FIGURE 3 DOMINANT TREE SPECIES IN THE THREE STUDY SITES

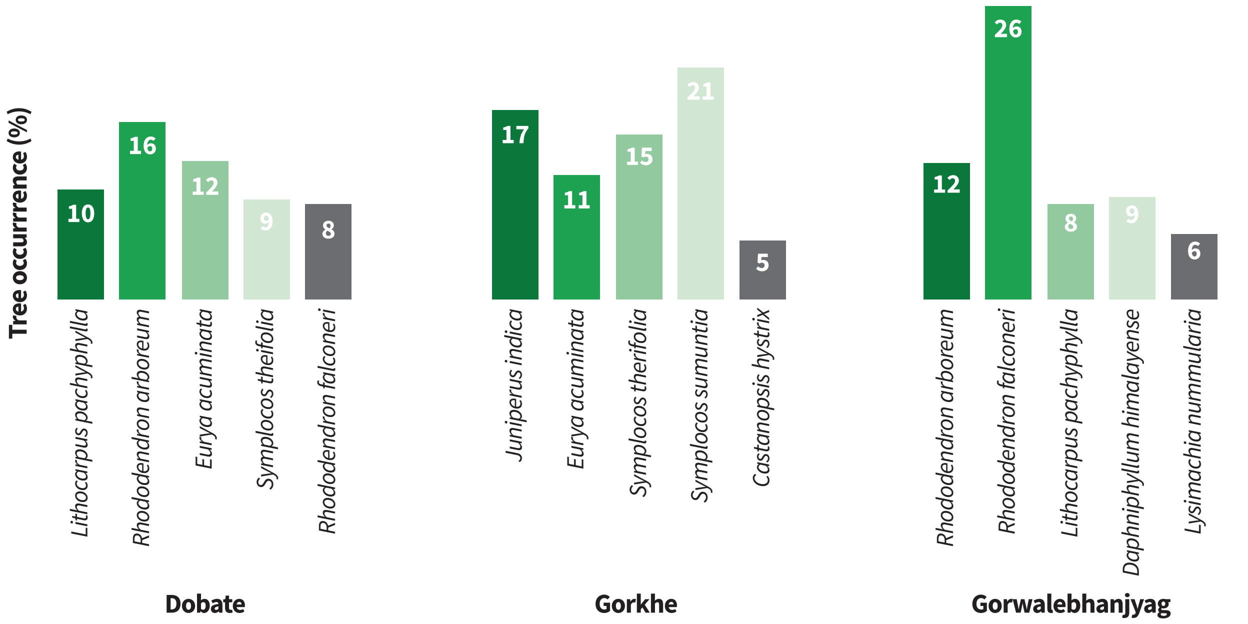


FIGURE 4 DIAMETER RANGE DISTRIBUTION

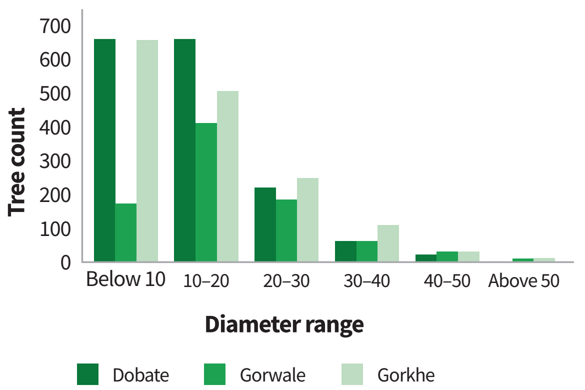
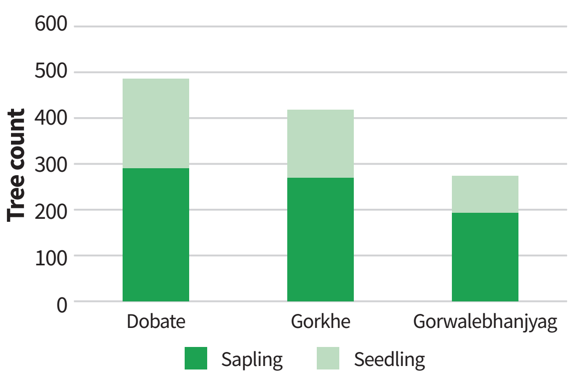


FIGURE 5 TOTAL SAPLINGS AND SEEDLINGS COUNT



forming around 37% and 39% of the total tree count.

Around 16% of the total tree count had the diameter range of 20–30 cm, 6% with 30–40 cm, and only 3% over the 40 cm range. Figure 4 gives a graphical representation of the range distribution across the study sites. The graph shows a noticeably large portion of the tree count to be under 20 cm dbh; so, with the information that we gathered, we could assume them to be young tree stands.

4.4 Saplings and seedlings count

Out of the total 2,860 saplings and seedlings counted in the study sites, 1,131 were saplings and 1,729 were seedlings. The total count of saplings and seedlings recorded in each study site is presented in Figure 5.

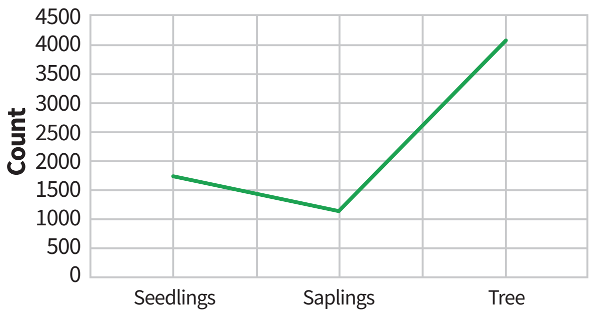
4.5 Forest structure

The highest recorded count represents a high carbon stock in the area and a higher number of seedlings is a sign of a regenerating forest. The J-shaped graph as shown in Figure 6 is considered a representation of an even-aged forest structure (Committee 2010; Karki et al. 2016b).

4.6 Forest biomass

Forest biomass estimation is a prerequisite for carbon estimation, bioenergy feasibility studies, and other analyses (Zhou et al. 2009). Using above-ground biomass is one of the methods to estimate the forest biomass of an area. The details of the biomass result are mentioned below:

FIGURE 6	STRUCTURE OF THE FOREST



4.7 Above-ground tree biomass

Dobate recorded the highest average biomass of 307 tonnes per hectare (t/ha) compared to the other two study sites. The Gorwalebhanjyag estimate is around 288 (t/ha) and the lowest average biomass was calculated in Gorkhe of 286 (t/ha). Table 2 below gives an insight into the biomass range, with a higher number of biomass falling in between the 200–400 range. This suggests the biomass enhancement possibilities of the forest.

4.8 Above-ground sapling biomass

The sapling biomass percentage of Dobate, Gorkhe, and Gorwalebhanjyag were 30%, 49%, and 21% respectively. Gorwalebhanjyag recorded the highest AGSB and the details are listed in Table 3.

4.9 Soil organic carbon

The soil organic carbon content was calculated across the sites which led to the following observations. The average carbon percentage within the 0–10 cm range was 10.5% and 7.5% in the 11–20 cm range (Table 4). The mean bulk density of the sample depth of 11–20 cm was higher than 0.11 g/cc. Gorwalebhanjyag had the highest soil organic carbon content with 183 t C ha, while Gorkhe had the lowest carbon content (173 t C ha).

4.10 Total biomass

The total biomass was estimated by summing up all the biomass stock at individual carbon pools (tree, sapling, and soil organic). The average biomass stock in all the three sites was 308 t ha (Annex 3). The above-ground tree biomass has a major share in the total biomass when compared to other two parameters, i.e. sapling/seedling and soil biomass. The details of each plot biomass are included in Table 5.

4.11 Carbon difference across plots

The highest and lowest carbon recorded across all the 42 plots was in plot Go10 and Go3 respectively (Figure 7). Since some of the plots were randomly generated to cover the heterogeneity of the study area, some plots fell in the grassland or sparsely

TABLE 2 BIOMASS RANGE OF ALL STUDY SITES

Biomass range (t/ha)	Tree Count
Below 200	10
200–400	22
Above 400	10

TABLE 3 SAPLING RANGE ACROSS THE SITES

Sites	AGSB (kg/ha)
Dobate	786
Gorkhe	537
Gorwalebhanjyag	1,262

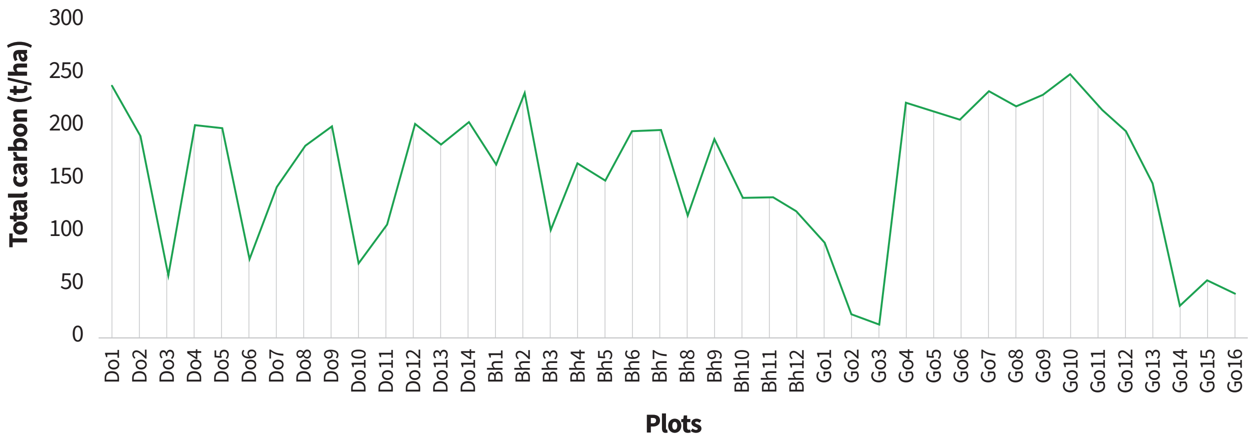
TABLE 4 SOIL ORGANIC AVERAGE INFORMATION

Sample depth (cm)	Bulk density (g cc)	Carbon percentage	Soil organic carbon
0–10	0.77	10.5	77
11–20	0.88	7.5	65

TABLE 5 AGB ESTIMATES PER STUDY SITE

Study sites	AGB (t/ha)	
	Mean	Range
Dobate	321	103.6–476.5
Gorkhe	307	180.74–218.16
Gorwalebhanjyag	298	13.7–237

FIGURE 7 PLOT-WISE CARBON RECORD



vegetated areas, resulting in a low biomass record. The highest recorded plot had *Juniperus indica* (dhupi), with a dbh range of 6–44 cm, and height ranging from 3–22 m. Gorwalebhanjyag showed the least carbon difference, while Gorkhe had the most carbon difference (Table 6).

As 76% of the plots recorded a carbon stock of over 100 tC/ha, relevant activities to improve the forest quality and its management could be carried out. The rest of the plots will possibly transition from being sparsely forested to densely forested through plantation activities.

TABLE 6 CARBON VALUES

Study sites	No. of plots	Highest–lowest carbon values (tC/ha)
Dobate	14	57–233
Gorwalebhanjyag	12	99–227
Gorkhe	16	12–246

SECTION V

Conclusion and future prospects

There is potential for undertaking plantation activities, especially of bamboo, for enhancing red panda habitat, and for more efficient and optimal use of existing forest biomass.

KEY MESSAGES

The abundance of young trees and high seedling count imply vigorous regeneration. By employing proper measures and conservation techniques, the forest cover can be further enhanced, thereby improving the overall carbon status.

The study provides estimation of forest biomass and carbon stock at three red panda habitats in Ilam district. Being the first of its kind, this study could be a baseline model for future forest biomass estimation and for further research. But, while all the above-ground biomass, including herbs, litter grass, deadwood, and stumps, were surveyed, they could not be successfully analysed as the field data got damaged. However, this data could be used as a field inventory to map the carbon stock, thereby giving us a unique opportunity to address the limited research in the area.

Vegetation dominance, forest biomass, and forest structure were calculated in altogether 42 sample plots, spread across an area of 2,740 ha. As the majority of the forest area is covered with young tree stands, the possibilities of enhancement of carbon sequestration can be worked on. A total of 64 different tree species were recorded from the study sites, with the most common being *Andromeda elliptica* (angeri), *Eurya acuminata* (jhigunne), and *Rhododendron arboreum* (gurans). Although their number might not be high, they were the most commonly occurring species in all the sites.

The majority of the plots had a biomass content between 200–400 t/ha, suggesting a medium-stocked forest, while the high count of seedlings implies vigorous regeneration. Since various factors affect the soil carbon, the content of soil organic carbon should not be taken as complete information when making recommendations for soil carbon enhancement. By employing proper measures and conservation techniques, the forest cover can be further enhanced, thereby improving the overall carbon status.

Taking the highest carbon value as the optimum point, we can enhance the carbon storage of the study area either by managing the biomass content or by plantation measures. The 10 plots with 100 tC/ha have the potential of plantation activities, preferably bamboos for red panda habitat suitability, while the remaining 32 plots can be managed more efficiently for carbon optimization over time by thinning and enrichment planting. The field data analysis can also be used in the future for mapping the carbon stock.

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Annexes

Annex 1: List of tree species

S. No.	Local name	Species	S. No.	Local name	Species
1	Arupate	*Prunus nepalensis*	33	Ghurpis	*Leucosceptrum canum*
2	Gurans	*Rhododendron arboreum*	34	Pipli	*Symingtonia populnea*
3	Asare	*Viburnum cordifolium*	35	Bajrath	*Quercus lamellosa*
4	Kapase	*Acer campbellii*	36	Chutro	*Berberis wallichiana*
5	Kholmen	*Symplocos sumuntia*	37	Champ	*Michelia lanuginosa*
6	Tenga	*Sorbus cuspidata*	38	Chimal	*Rhododendron lindleyi*
7	Bhalu chinde	*Schefflera impressa*	39	Lokta	*Daphne bholua*
8	Kharane	*Symplocos theifolia*	40	Saur	*Betula cylindrostachys*
9	Pahenle	*Litsea elongata*	41	Kukurpaile	*Acer sterculiaceum*
10	Korlinga	*Rhododendron falconeri*	42	Siris	*Albizia procera*
11	Kaulo	*Machilus edulis*	43	Nimaro	*Ficus rosenbergii*
12	Bante	*Lithocarpus pachyphylla*	44	Liso	*Ilex fragilis*
13	Sisi	*Cinnamomum impressinervium*	45	Silinge	*Lysimachia nummularia*
14	Timbur	*Zanthoxylum armatum*	46	Panch pate	*Vitex heterophylla*
15	Tarsing	*Beilschmiedia roxburghiana*	47	Simal	*Pinus wallichiana*
16	Dabdabe	*Garuga pinnata*	48	Patpate	*Gaultheria fragrantissima*
17	Seti Kath	*Endospermum chinense*	49	Lautsalla	*Taxus wallichiana*
18	Khanakpa	*Evodia fraxinifolia*	50	Chandan	*Daphniphyllum himalayense*
19	Phalant	*Quercus lineata*	51	Dhupi	*Juniperus indica*
20	Bhadrase	*Elaeocarpus sikkimensis*	52	Dudhilo	*Ficus neriifolia*
21	Jhigunne	*Eurya acuminata*	53	Phaledo	*Erythrina arborescens*
22	Bhalayo	*Rhus succedanea*	54	Rani salla	*Pinus roxburghii*
23	Katus	*Castanopsis hystrix*	55	Simal	*Bombax ceiba*
24	Phalamen	*Walsura tubulata*	56	Okhar	*Juglans regia*
25	Angeri	*Andromeda elliptica*	57	Tite champ	*Michelia cathcartii*
26	Uttis	*Alnus nepalensis*	58	Chilaune	*Schima wallichii*
27	Malata	*Macaranga pustulata*	59	Mahuwa	*Engelhardtia spicata*
28	Painyun	*Prunus cerasoides*	60	Latikath	*Glochidion acuminatum*
29	Gogan	*Saurauia nepalensis*	61	Musure katus	*Castanopsis tribuloides*
30	Chuletro	*Brassaiopsis hainla*	62	Arkaulo	*Quercus fenestrata*
31	Bogate	*Maesa macrophylla*	63	Katus	*Casearia glomerata*
32	Lampate	*Duabanga sonneratioides*	64	Siltimur	*Litsea cubeba*

Annex 2: Plot-wise count of trees, saplings, and seedlings

Plot	Tree count	Sapling count	Seedling count
Do1	103	16	60
Do2	101	6	27
Do3	33	34	17
Do4	95	36	35
Do5	94	46	58
Do6	73	37	31
Do7	79	35	21
Do8	254	82	189
Do9	208	77	136
Do10	66	9	28
Do11	83	27	49
Do12	170	32	72
Do13	98	22	47
Do14	255	60	87
Bh1	87	9	21
Bh2	101	11	13
Bh3	50	17	6
Bh4	57	13	3
Bh5	102	14	52
Bh6	96	12	26
Bh7	81	18	16
Bh8	36	6	8
Bh9	32	59	56
Bh10	26	17	164
Bh11	45	8	13
Bh12	108	5	9
Go1	101	15	19
Go2	35	5	3
Go3	2	0	0
Go4	58	22	6
Go5	61	25	20
Go6	47	12	7
Go7	151	63	40
Go8	142	56	70
Go9	182	60	44
Go10	149	40	54
Go11	236	39	14
Go12	165	8	20
Go13	88	27	88
Go14	56	11	6
Go15	46	28	50
Go16	11	10	42

Annex 3: Total biomass

Plot ID	Tree biomass (t/ha)	Sapling biomass (t/ha)	Soil carbon (t/ha)	Total biomass (t/ha)
Do1	458.8943501	0.05730368	17.6078	476.5594537
Do2	368.2794499	0.0239323	15.3812	383.6845822
Do3	86.89035247	0.116221167	16.6732	103.6797736
Do4	389.7820952	0.102509082	14.5747	404.4593043
Do5	390.75329	0.177547087	10.5909	401.5217371
Do6	127.7576268	0.14433617	11.7425	139.644463
Do7	270.3220827	0.042976529	14.8852	285.2502592
Do8	368.9290282	0.051176946	5.8234	374.8036051
Do9	387.2607845	0.012972956	15.5151	402.7888575
Do10	115.1944836	0.018502647	13.9849	129.1978862
Do11	211.0651718	0.010044684	5.4958	216.5710165
Do12	390.5245167	0.010554093	16.1053	406.6403708
Do13	355.7902006	0.012404878	12.4643	368.2669055
Do14	389.8851573	0.0002299	17.4361	407.3214872
Bh1	302.7330839	0.021262795	17.5092	320.2635467
Bh2	447.1433521	0.045261651	16.9884	464.1770138
Bh3	153.7671028	0.050859416	26.9249	180.7428622
Bh4	308.2899956	0.041280716	17.6213	325.9525763
Bh5	271.0877547	0.032127981	16.5325	287.6523827
Bh6	375.3475867	0.057718011	16.5975	392.0028047
Bh7	357.5904287	0.045732532	25.089	382.7251613
Bh8	203.9791763	0.040565893	16.456	220.4757422
Bh9	356.1947315	0.093770069	17.8254	374.1139016
Bh10	236.0533601	0.062490957	18.9815	255.097351
Bh11	241.3076812	0.029238486	16.842	258.1789197
Bh12	211.0599454	0.017144323	17.3808	228.4578897
Go1	167.3761036	0.037955174	10.1235	177.5375588
Go2	30.11541057	0.002600811	7.1734	37.29141138
Go3	2.666000607	0.0012	11.084	13.75000061
Go4	451.1356606	0.001654836	5.7835	456.9208155
Go5	429.9213545	0.00284394	7.5063	437.4304984
Go6	408.5706916	0.01130381	11.3214	419.9033954
Go7	451.2747377	0.183379596	16.5448	468.0029173
Go8	428.9260816	0.178341751	13.7291	442.8335233
Go9	468.3316107	0.141048371	5.8921	474.3647591
Go10	487.4388556	0.181033851	16.6406	504.2604895
Go11	422.535623	0.168475916	17.522	440.2260989
Go12	370.7084796	0.005859249	18.0824	388.7967388
Go13	266.9759889	0.151555356	17.4654	284.5929442
Go14	26.03754299	0.054315425	15.9478	42.03965841
Go15	104.0709184	0.113519303	4.5118	108.6962377
Go16	68.30610804	0.028331272	9.1968	77.53123931

Annex 4: Data collection sheets

Forest carbon measurement 2018
Tree inventory with dbh greater than 5 cm at plot 20x20 m
Plot:
Subplot:
Latitude:
Longitude:
Rural Municipality:
Village:
Forest strata:
Aspect:

Tree species	Scientific name	Age	Clinometer (%)	Distance	Observer's height	Tree height	DBH	Canopy coverage

Annex 5: Data collection sheets (Soil)

Site Number: .... Date: ....

		Remarks
Geographical Position	Region	
	Latitude	
	Longitude	
	Elevation	
Weather	The day	
	The past week	
	Air temperature	
Topography	Terrain	
	Slope aspect	
	Slope position	
Soil information	Soil type	
	Surface feature	
Bulk density	Fresh weight (g)	

Annex 6: List of instruments, equipment used

GPS	Locating plots
Base map	For reference, navigation
Rope	Boundary delineation
Plastic bags	To collect samples of leaf, litter, and soil
Marker	To mark the trees
Weighing machine	To weigh samples
Scissors	To cut herbs, grass
Shovel	To dig soil
Linear tape	To measure the distance between tree and measurer
Diameter tape	To measure the diameter of the tree at breast height
Clinometer	To measure ground slope, top, and bottom angles to the tree
Vertex	To measure tree height
Sieving	To sort the soil sample
Soil sample rings	Three rings for soil depth and soil carbon sample

About ICIMOD

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 Himalaya – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and based in Kathmandu, Nepal. Globalisation 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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