

Contributions by the Private Sector to Climate Change Mitigation: Lessons from the Plantec Coffee Estate in Nepal

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Contributions by the Private Sector to Climate Change Mitigation: Lessons from the Plantec Coffee Estate in Nepal

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Foreword

The Hindu Kush Himalaya is seeing a reduction in productivity of the agricultural sector, with increasing reliance on a remittance-based economy; this makes the mountain economy highly vulnerable as it fails to attract productive investment that supports local production and businesses. This has given rise to an increase in underutilized lands and barren landscapes; accordingly, attracting investment in the mountains for sustainable management of the landscape is a challenge.

This working paper is innovative as it examines two aspects that are central in the development discourse of the mountain landscapes. First, it shows how a private sector can be attracted to a business model that generates profit and at the same time also enhances carbon sequestration, conserves biodiversity, and generates local employment. Second, it illustrates how a private sector can contribute to the broader objectives of REDD+ by converting a totally barren land to forest cover with a shade-grown coffee plantation in less than two decades, even though this business was not designed for carbon credits.

In the global REDD+ discourse, private sectors related to forestry and agriculture enterprise are seen as the major underlying drivers for deforestation and forest degradation. In addressing these drivers, deforestation free value chains and involving the private sector in REDD+ are important aspects. Furthermore, the REDD finance available is short of addressing the goals of the New York Declaration on Forest; thus, the private sector will be an important source for filling this resource gap. Despite the importance of the private sector, there is no clear guidance on how businesses can be motivated to play a role. Therefore, this paper highlights one example of how the private sector can adopt a business model in which a business can promote a sustainable environment while earning a profit.

The lessons from this paper illustrate an approach to developing a green enterprise based on nature's blueprint and founded on community development. The carbon stock found in this shaded coffee plantation was more than those found in many other forests under community management. The plantation now harbors many birds and wildlife species, which was not the case when the land was barren.

I am thankful to the Plantec Coffee Plantation of Nuwakot and the team from ICIMOD that worked together to document this case study. This study is intended to encourage private sector to make investment in green enterprise in the region that will yield multiple dividends: profits, sustainable environment, carbon sequestration, biodiversity conservation, and community employment opportunities. This approach not only addresses environmental sustainability, but is also a sustainable business model that receives a premium price for its production system from the international market for exported coffee.

I would like to express our gratitude to all the authors and editors for articulating the role private sector can play in sustainable landscape management.

David J. Molden, PhD
Director General
ICIMOD

Acronyms and Abbreviations

AGB	Above-ground biomass
AGSB	Above-ground sapling biomass
AGTB	Above-ground tree biomass
BGB	Below-ground biomass
CB	Coffee biomass
CDM	Clean development mechanism
DBH	Tree diameter
DoS	Department of Survey
GCS	Geographic coordinate system
GHG	Greenhouse gas
GIS	Geographic information system
GPS	Global positioning system
Ha	Hectare
HKH	Hindu Kush Himalaya
INDC	Intended nationally determined contribution
IPCC	Intergovernmental panel on climate change
LHG	Leaf litter, herbs, and grass
LHGB	Biomass of litter and herb/grass
NDC	Nationally determined contribution
RMS	Root mean square
SOC	Soil organic carbon
tCO ₂	Tones Carbon Dioxide
tC/ha	Tones Carbon per Hectare
USGS	United States Geological Survey
WGS	World geodetic system

Executive Summary

Agroforestry in the Hindu Kush Himalaya (HKH) is a suitable biological mitigation intervention that contributes to NDC targets and REDD+ objectives. With that in mind, this paper attempts to demonstrate the ways in which a private sector business has established an agroforestry system on 38.5 ha and its role in increasing carbon stock. Temporal sets of aerial photographs, satellite images, and matched pairs of field photographs were used to illustrate the development of shaded coffee agroforestry over a 20-year period. Before the establishment of agroforestry (1994), the land use was dominated by cultivated land (73.2%), barren land (17.1%), and shrubs/bushes (6.3%). At the present (2016), 31.2 ha (81.2% of the area) is covered with forest, of which 52% has a closed canopy. The average total carbon stock of the area was found to be 176.5 tC/ha which would relate to 647.76 tCO₂/ha. At USD 5 per tCO₂, the total value of carbon sequestered by this estate over a 20 year period would be approximately USD 124,693.

This study illustrates how a private sector company – Plantec Coffee Estate (P) Ltd. – was able to achieve a positive change in restoring degraded landscape through private investment. The study results suggest that the role of agroforestry for meeting the REDD+ targets could be significant. Additionally, it demonstrates the feasibility of private sector investment in REDD+ activities. Both of these findings pave the way for replicating the active involvement of the private sector in the restoration of degraded lands and contributing to the REDD+ objectives through agroforestry interventions.

Key words: REDD+, Carbon stock, Forest restoration, Land use and land cover, Private sector, and Agroforestry

Introduction

Agroforestry research and development has come to view trees outside of forests as a landscape-level system which can play a significant role in the provision of environmental services and livelihoods for local communities. Agroforestry has roots in both agriculture and forestry and can be seen as the interaction of two – describing landscapes and farming systems that are between monoculture cropping and monoculture plantation. An “ecosystems approach” to forests, as part of wider social landscapes and land use patterns, has recently become better appreciated, and is now an accepted part of international environmental law (Sayer & Maginnis, 2007). Agroforestry plays an important role in improving the resilience of farming systems to climate variability. Integrating trees in agriculture creates a carbon sink in the field by sequestering carbon; at the same time it also reduces emissions by decreasing the pressure on other forest areas and increasing the availability of timber and non-timber forest products from agricultural fields (MacDicken, 1997). Yet, at the same time, detailed research has shown that traditional societies have long managed and transformed their wider landscapes as integrated wholes. It is important to understand that agroforestry is viewed both as an approach to land use and as a set of integrated land use practices (Sinclair, 1999).

In many parts of the world, agroforestry approaches and practices can be particularly relevant for addressing the nexus of efforts to (1) reduce poverty and hunger and (2) ensure environmental sustainability. Agroforestry is uniquely placed in terms of related mitigation options; it can be designed and implemented to be compatible with adaptation strategies and can have substantial co-benefits in terms of biodiversity, employment, watershed conservation, and income generation while simultaneously enhancing the terrestrial carbon pool. In addition, agroforestry may also be able to improve the resilience of livelihood systems to shocks associated with periodic crop failures caused by the impact of climatic or market fluctuations on particular production components (Ataroff & Monasterio, 1997). It provides a more resilient platform for adaptation to future climate change (Jose, 2009), largely because it maintains a higher floral diversity than farming systems.

Agroforestry is already widely practiced on all continents. Remote sensing data show that in 2010, 43% of all agricultural land globally had at least 10% tree cover, and that this constitutes an increase of 2% over the previous ten years (Zomer et al., 2016).

Since the Paris Agreement 2015, the role trees can play in reducing greenhouse gas (GHG) emission has gained more attention as an important strategy for achieving the Intended Nationally Determined Contribution (INDC) target and also REDD+ objectives. INDC identifies the commitment from national governments to the Paris Agreement 2015 of the UNFCCC for post-2020 global emission reduction. REDD+ objectives are a voluntary activity for developing countries to reduce emissions from deforestation and forest degradation, conservation, sustainable management of forests, and enhancement of forest carbon stocks (REDD+).

Both strategies endorsed by the Hindu Kush Himalaya (HKH) countries rely on maintaining forest area and increasing tree cover. Agroforestry in the HKH is a suitable biological mitigation intervention that contributes to NDC targets and REDD+ objectives. Countries are committed to meet their NDC targets by increasing tree cover outside of existing forests, and this is where agroforestry will be an important intervention for implementing the NDCs and REDD+.

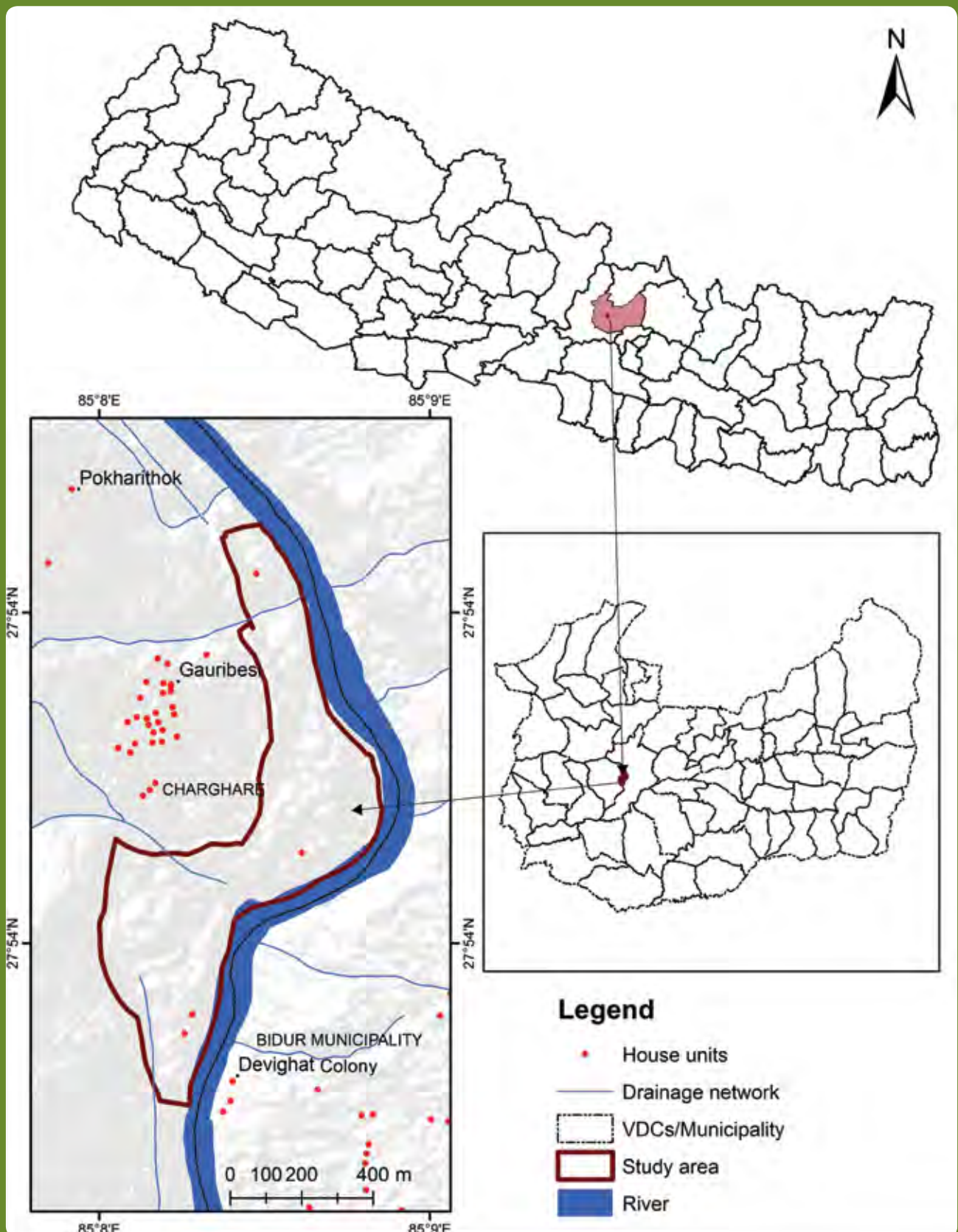
Though this has been a traditional practice in the HKH for centuries, it builds on the synergistic interactions between woody and non-woody components to increase the productivity and diversity of the landscape and simultaneously enhance its sustainability (Denholm, 1987). The multiple potential benefits of agroforestry systems are attracting not only farmers but also the private sector as well. This paper examines a successful case of multiple social, environmental, and economic benefits as a result of private sector investment in converting a previously degraded and barren land into a shaded coffee plantation. The presence of trees on shade-grown coffee farms not only supports the production of coffee, which has high economic value, but also creates local-level employment, especially for women.

Study Area

The Plantec Coffee Estate (P) Ltd. field site is located in Charghare VDC, near the Battar bazar of Nuwakot district (Latitude-27.901787° E and Longitude 85.137401°N), at an altitude of 515-530 m above sea level, 70 km north of the capital, Kathmandu, Nepal (Figure 1). The land is leased from the government for a duration of 40 years, and is spread over 68 ha, out of which about 38.5 ha is covered by shade-grown coffee plantation; this was the study area. This estate was registered and established in 1994 to grow and process fully organic 100% high quality Arabica (Caturra) coffee beans for export. Plantec Coffee Estate's mission is to grow shade grown coffee as indirect sunshine allows slow ripening to contribute to fine flavors. Present buyers are among the foremost specialty green bean importers in Europe, The product is branded "Jalpa Gold" for regional sales and "Mount Everest Supreme" for export.

The plantation was established on barren/fallow land, including some traditional agriculture lands. This area underwent complete afforestation with tree species consisting of *Dalbergia sissoo*, *Leucaena leucocephala*, *Michelia champaca*, *Melia azedarach*, and *Albizia lebbeck*, among others, in 1994. The site has been creating jobs locally for the area's marginalized indigenous communities, who have limited livelihood options. The plantation's major source of income is the coffee beans that it processes for export. Locally, it hands over the timber to the local school whenever the prunings take place, so the school can sell and deposit the amount in the school fund. This plantation has now seen an increased sighting of various species of birds, wild fowl, and other wild animals like the barking deer, common leopard, and jackal.

Figure 1: Study area



Methodology

The methods used in this study are divided into two parts: 1) *In-situ* measurement: boundary delineation study area, collection of ground samples for biomass estimation, and repeat photographs to visualize landscape changes; 2) Remote sensing measurement (aerial and satellite): to assess the land cover changes. Additionally, landowner and manager interviews were conducted to collect land management information, including published data and historic photographs.

In-situ Measurement

Boundary delineation

The original estate boundary was available via hardcopy map. By taking the reference of the hardcopy map, the Global Positioning System (GPS) receiver was used to delineate the digital boundary in Geographic Information System (GIS) format (.shp). A staff member of the estate carried a GPS receiver to delineate the designated boundary of the leased area (Figure 2). The delineated boundary is taken further to extract a satellite-derived traits comparison.

Field data collection

A total of six stratified random sampling plots were identified for the field data collection (Figure 2). The selection was made in the field on the basis of tree species and coffee plant density that embodies the estate area.

The main equipment used in the field work is shown in Table 1. A GPS was used for finding the position of the sample plots and recording the centre. Tree diameter (DBH) was measured using diameter tape, and tree height was measured with a Vertex IV with a transponder. Field data collection forms were used to record field information.

For sample design Figure 3 and biomass/carbon stocks estimation, the methodology was adopted from Subedi et al., (2010), developed for the community-managed forests.

For Above Ground Tree Biomass (AGTB), the DBH (at 1.3 m) and height of individual trees greater than or equal to 5cm DBH were measured in each permanent circular 250 m² plot, which was 8.9 m in radius using diameter tape, clinometers, and linear tape, starting from the edge and working inwards, and marking each tree to prevent accidentally counting it twice. Highly sensitive equipment such as a Vertex IV with a transponder was used to measure tree height directly. Each tree was recorded individually with its species' name. Trees on the border were included if >50% of their basal area was within the plot and were excluded if <50% of their basal area falling outside the plot. Trees overhanging into the plot were excluded, but trees with their trunks inside the sampling plot and branches outside were included.

Nested subplots having a 5.6 m radius inside larger plots were established for assessing the above ground biomass and regeneration of sapling. Smaller nested subplots having a 1 m radius inside the larger nested plots were established for assessing regeneration. Saplings with diameters of >1 cm to <5 cm were measured at 1.3 m above ground level, while saplings smaller than 1 cm in diameter at 1.3 m above ground level were counted as regeneration.

One circular subplot of one square meter (0.56 m radius) in size was established at the center of each plot to assess leaf litter, herbs, and grass (LHG). All the litter (dead leaves, twigs, and so forth) within the 1 m² subplots were collected and weighed. Approximately 100 g of evenly mixed sub-samples were brought to the laboratory to determine moisture content, from which total dry mass was calculated. Likewise, herbs and grass (all non-woody

Table 1: Field equipment used for field data collection

Equipment	Purpose
Garmin GPS and iPAQ	Location
Diameter tape (5 m)	Measuring tree diameter
Measuring tape (30 m)	Measuring the plot radius
Vertex IV with transponder	Height measurement
Field work datasheet	Field data collection

Figure 2: Sample plot locations in delineated boundary

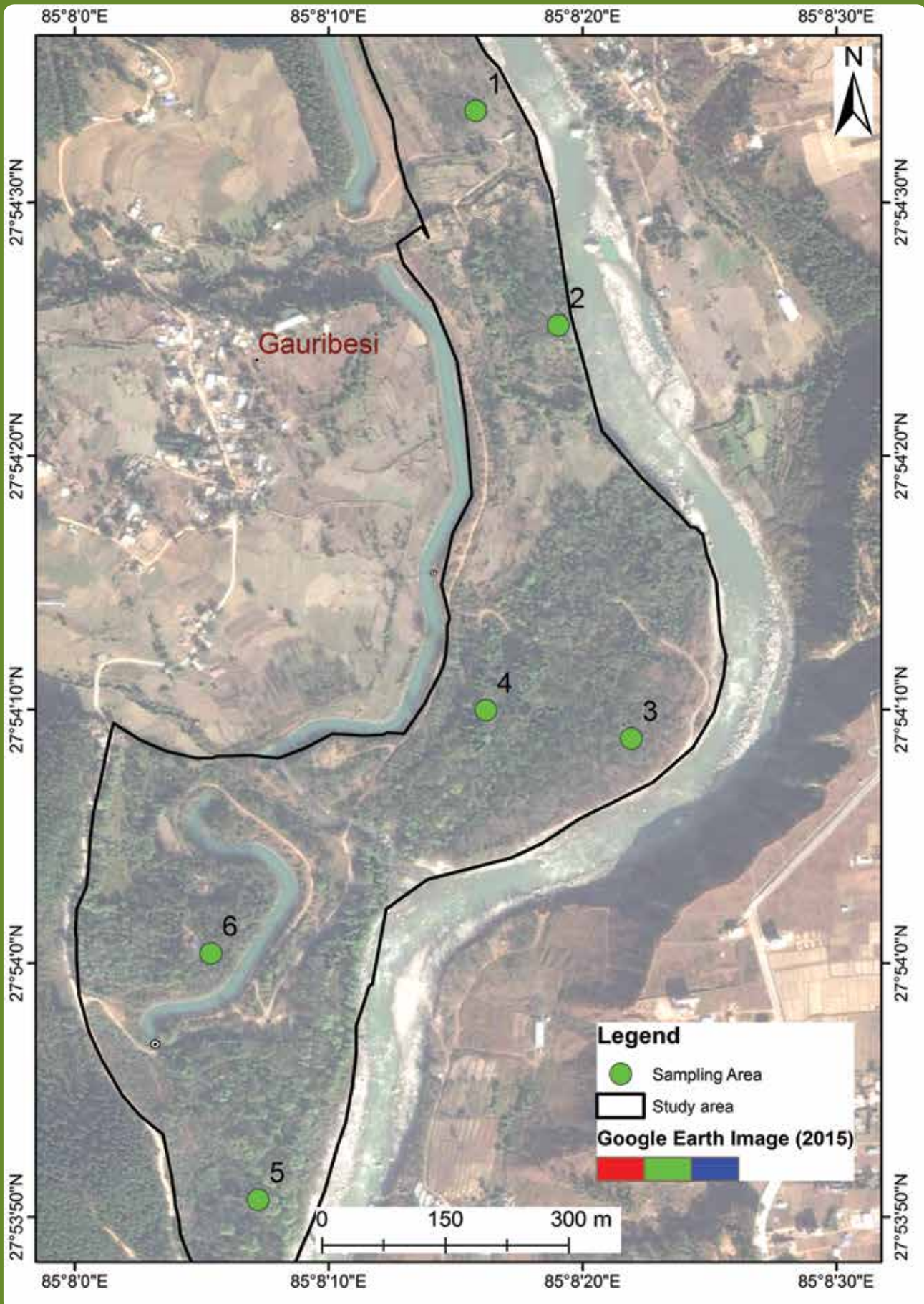
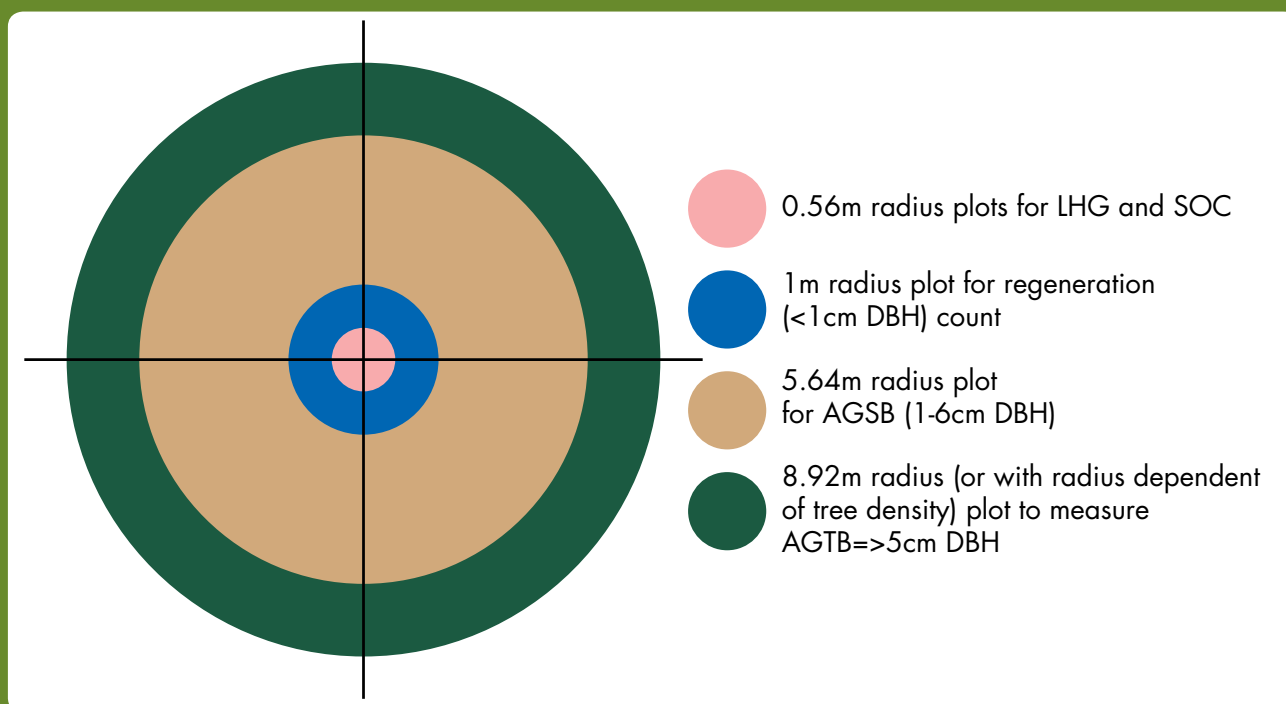


Figure 3: Sampling design



Adopted from Guidelines for measuring carbon stocks in community-managed forests.

plants) within the plots were collected by clipping all the vegetation down to ground level, weighing it, placing it in a sample weighing bag, and bringing it to the laboratory to determine the oven dry weight of the biomass. Soil Organic Carbon (SOC) was determined through samples collected from the default depth prescribed by the IPCC (2006).

Near the center of all plots and/or sub-plots a single pit of up to 30 cm in depth was dug to best represent forest types in terms of slope, aspect, vegetation, density, and cover. The location of the hole was chosen based on the foresters' knowledge of the area. For the purpose of estimating bulk density, three individual soil samples of approximately 100 cm³, one each from three depths (0-10 cm, 10-20 cm, and 20-30 cm) were collected. Similarly, one composite sample was collected, mixing soils from all three layers in order to determine concentrations of organic carbon and then weighed at a precision of 0.1 g. Approximately 100 g of composite sample were collected from each plot.

For destructive sampling of coffee, only three coffee plants were cut down, uprooted, and weighed (fresh weight), and subsamples of parts of the vegetation (understory biomass, coarse litter, branches) were taken, weighed fresh in the field, and weighed again after oven-drying. Coffee bushes do not have biomass and volume equations, so the entire plant had to be uprooted and weighed.

Biomass/Carbon Stocks Estimation

The allometric equation-1 given by Chave et al., (2005) for tropical moist hardwood forests was used for above-ground tree biomass (AGTB). Wood-specific gravities for each tree species were taken from the values published by Chaturvedi & Khanna, (1982), available under MPFS (1988). The sum of the AGTB (in kg) of all individual trees in the sample plot was divided by the area of the plot to give the average AGTB density in kg/m². This value was then converted to tonnes per hectare (t/ha) using scale factor. Since the project area has both tropical and subtropical vegetation, the biomass value was converted into carbon stock by multiplying with the default carbon fraction of 0.47, as suggested by the IPCC (2006).

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

Where AGTB = above ground tree biomass (kg), ρ = wood-specific gravity (kg/m³), D = Tree Diameter at Breast Height (DBH in cm), and H = Tree Height (m).

Similarly, coffee biomass (CB) within a plot was computed through multiplication of total coffee present and the average biomass of the destructive sample. The sapling biomass was estimated as nil because saplings with diameters of >1 cm to <5 cm were not found within our sampling plots.

Likewise, biomass of litter and herb/grass (LHGB) was analyzed by referring to the guidelines prepared by (Subedi et al., 2010). Below-ground biomass (BGB) was estimated as 15% of above-ground tree biomass (MacDicken, 1997) to maintain a conservative estimate. Additionally, carbon content in AGB, CB, and LHGB were calculated by multiplying the respective value by 0.47 (default carbon fraction) as suggested by (IPCC 2006), while soil organic carbon was calculated by averaging the SOC value obtained as per Pearson et al., (2007) equation-2.

$$SOC = \rho \times d \times \%C \quad (2)$$

Where

SOC = Soil organic carbon stock per unit are ($\frac{t}{ha}$)
 ρ = Soil bulk density ($g\ cm^{-3}$)
 d = the total depth at which the sample was taken (cm)
 $\%C$ = carbon concentration (%)

Finally, total carbon was calculated using equation-3.

$$C\ (Plantec\ coffee\ estate) = C\ (AGTB) + C\ (CB) + (LHGB) + C\ (BGB) + SOC \quad (3)$$

To convert carbon to carbon dioxide (CO₂), carbon was multiplied by 44/12 (the ratio of the molecular weight of carbon dioxide to carbon).

Land Cover and Land Use Change Analysis

Land cover change is a multidisciplinary subject being studied largely by social and natural resource scientists in different parts of the world at various scales. At the local scale, most proximate sources change the land cover, the consequences of which are eventually observed at national to global scales. In this study, in order to understand land cover changes, especially looking into the transition from barren/agriculture to trees, historic and present remote sensing and field photographs were incorporated.

Remote sensing images

As the study area is very small, high resolution remotely-sensed data were used to assess the land cover changes (visually as well as digitally). In 1994, this area was taken under the lease from the government and the shaded coffee plantation was started. To assess the pre-lease condition, aerial photos of 1991 were taken under consideration. Acquiring remotely-sensed data at equal intervals is very challenging and occasionally impossible due to a number of factors (sensor temporal frequency and weather conditions). So the best available remotely-sensed data from different sources were collected and utilized (Table 2).

Pre-processing of Image

Two 1:12,500 scale aerial photos of 1991 and 1996 were scanned at 1200 dpi. A GeoEye-1 satellite image was downloaded from Google Earth Pro, which was rectified by taking 20 ground control points from the Google Earth image by using 1st order polynomial (Affine) transformation with a root mean square error (RMS) of 0.00002. Then, the image was projected to a geographic coordinate system (GCS) with datum 1984. Similarly, scanned aerial photos of 1991 and

Table 2: Image description and source

Image description	Acquisition year	
Aerial photo	1991	DoS, GoN
Aerial photo	1996	DoS, GoN
OrbView-3	2004	USGS
Google Earth image	2015	Google Earth Community

Department of Survey (DoS), Government of Nepal
United States Geological Survey (USGS)

1996 were rectified by using the same procedure, each having a RMS error of 0.00009. The Orbview-3 has a World Geodetic Survey 1984 (WGS 84) projection system, which made it compatible with other pre-processed images. In all four datasets, spatial compatibility was observed, which is essential for accurate land cover and land use mapping and change analysis.

Land cover and land use mapping

A on-screen digitization technique was adopted to develop land cover and land use maps through remotely-sensed datasets. Using visual image interpretation on the basis of shape, size, pattern, tone, shadow, and association of features, altogether eight present land cover and land use classes in the study area were identified and mapped. ArcMap was used for the digitization of land cover and land use polygons, depending on the existence in respective years, and their land cover and land use types were added to the attribute table. Land cover and land use maps for 1991, 1996, 2004, and 2015 were evaluated and compared in terms of area.

Visual Interpretation of Remotely-Sensed Images and Terrestrial Photographs

A visual image interpretation technique was used to investigate the differences and similarities between the baseline and recent remotely-sensed data and filed photographs of the study area. Historical photographs are regarded as an important tool to examine and understand the temporal extent of both surficial physical and biological processes (Niraula et al., 2013). A matched pair of photographs were used to study changes in vegetation and land use in different parts of the world (Cerney, 2010; Hart & Laycock, 1996; Nüsser, 2000, 2001; Smith, 2007). Through swiping techniques among the aerial photos of 1991 and 1996, OrbView-3 (2004), and GeoEye-1, Google Earth image (2015) temporal changes were identified and reported. In this study, baseline field photographs of 1995 were collected from the landowner and geo-tagged. With the help of the landowner and field staff, once again in 2016, fixed point photographs were taken at selected sites to examine changes in the study area.

Data analysis

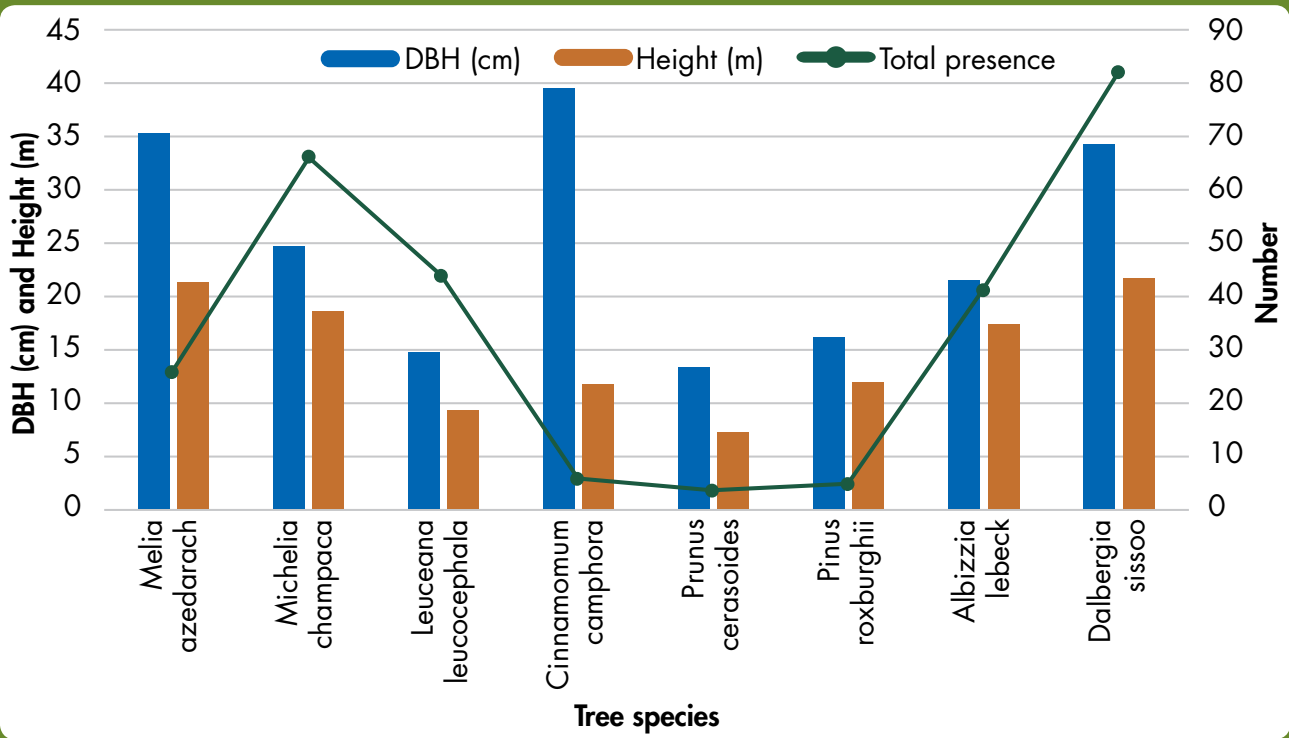
Data collected from the field, lab, and generated through RS/GIS analysis were analyzed with simple statistical procedures in Excel and presented in Figures and Tables.

Results

Field Data – Tree Species and Plot Level Analysis Information

Altogether, eight tree species were identified and measured in the study area. The average height and DBH were analyzed and revealed that *Cinnamomum camphora* (Kapoor) is the tallest tree, while *Dalbergia sissoo* (Sissoo) species had the highest numbers of DBH among other tree species. Similarly, the most numerous species was *Dalbergia sissoo*, followed by *Michelia champaca* (Figure 4).

Figure 4: Height and DBH of the tree species and total number of tree species



In the whole study area, six random sample plots were measured in the field. Plot 1 had the greatest height and DBH, Plot 3 had the lowest DBH, and Plot 5 had the least height (Figure 5). In addition, eight tree species were explored and identified in the area. *Dalbergia sissoo* had the highest AGB, while *Prunus serasoides* had the least. The high AGB level of Sisso (*Dalbergia sissoo*) can be attributed to their significantly greater numbers (Figure 6).

Carbon Stock Estimation

The average total above-ground carbon, below-ground carbon, and soil organic carbon in the Plantec Coffee estate were calculated to be 95.9 tC/ha, 103.2 tC/ha, and 57.8 tC/ha, respectively, which

Figure 5: Height and DBH of the tree species

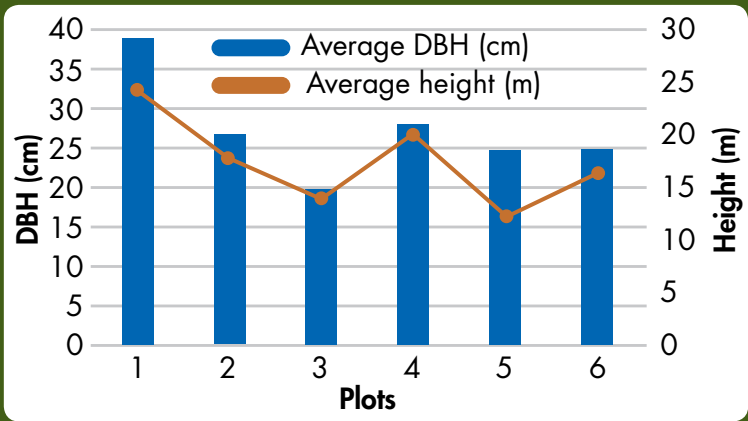
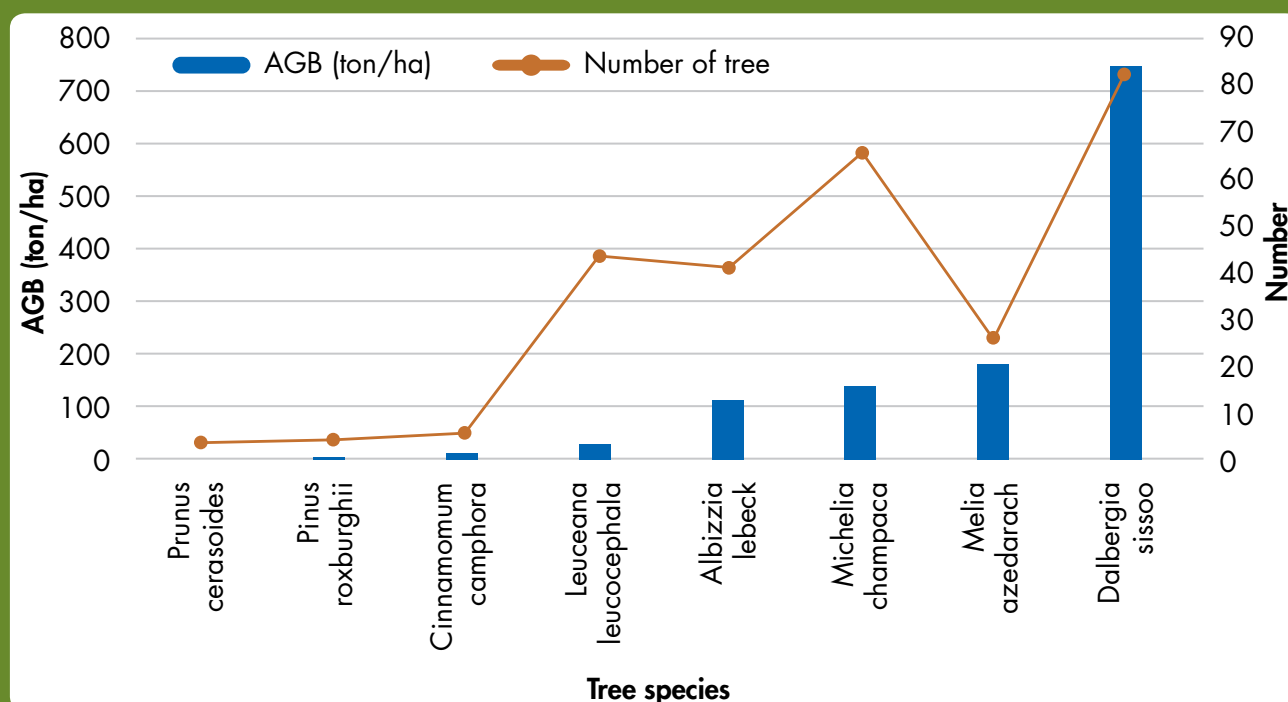


Figure 6: Number of trees and their above-ground biomass



collectively contributed to the total carbon stock of an area. Thus, the average carbon stock of an area was 176.5 tC/ha. Similarly, average coffee carbon and litter/herb/grass carbon were calculated to be 2.4 tC/ha and 4.9 tC/ha (Table 3).

Table 3: Carbon stocks from biomass and soil

Plot No.	Above-ground tree carbon	Litter, herb/grass carbon	Coffee carbon	Total above-ground carbon	Below-ground carbon	Soil organic carbon	Total carbon stocks
	tC/ha						
1	168.8	3.8	3.6	176.2	26.4	50.50	253.1
2	63	7.2	2.7	72.9	10.9	57.40	141.2
3	90.8	3.6	1.3	95.7	14.4	58.90	169
4	90.7	4.3	2.4	97.4	14.6	67.90	179.9
5	46.9	6.6	2.4	55.9	8.4	56.60	120.9
6	115.1	4.1	2.3	121.5	18.2	55.70	195.4
Average	95.9	4.9	2.4	103.2	15.5	57.8	176.5

Land Cover and Land Use Maps

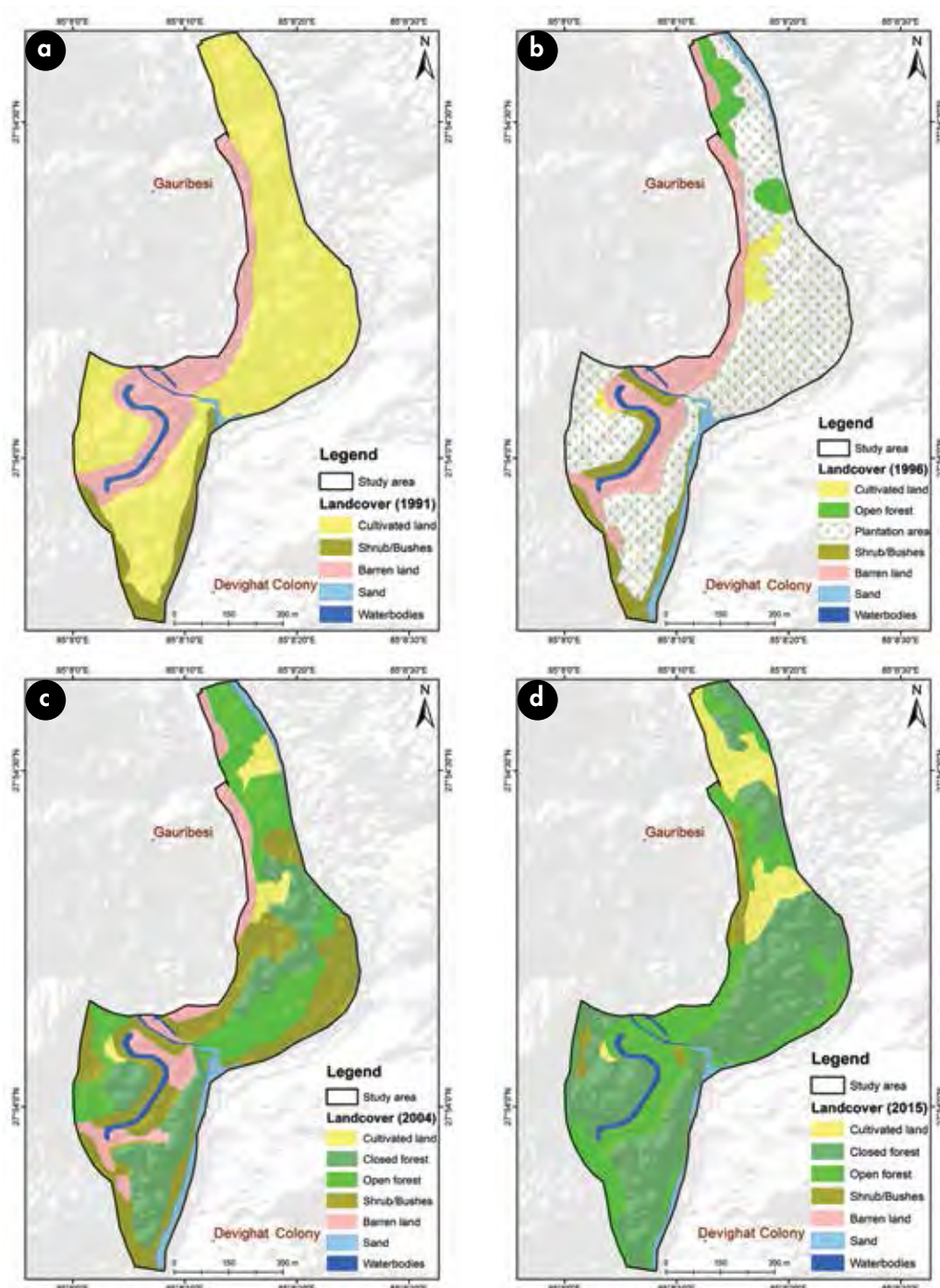
During 1991, the land cover of the study area was dominated by cultivated land (73.2%), followed by barren land (18.1%) and shrub/bushes (6.3%). During 1991-1996, a total of 22.6 ha (58.8% of total land) of the cultivated land was converted into shaded coffee plantation area. Similarly, two small patches of forest with sparse canopy were developed in the northern part of the study area.

During the eight-year period of 1996-2004, barren land was reduced by 2.8 ha and forest cover increased because of agroforestry practices. However, the forest was in an early stage of succession; 8.6 ha (22.3%) and 9.7 ha (25.2%) of land were covered by the closed and open forest, respectively. Presently, 81.2% of the area is covered by the forest, out of which 52% has a closed canopy. From 2004 to 2015, 10.6 ha of shrub/bushes were converted into forest (Table 4 & Figure 7).

Table 4: Land use of Plantec Coffee Estate in 1991, 1996, 2004, and 2015

Land cover (Area in ha)	1991 (ha)	1991 (%)	1996 (ha)	1996 (%)	2004 (ha)	2004 (%)	2015 (ha)	2015 (%)
Closed forest	0	0	0	0	8.6	22.3	20	52
Open forest	0	0	2.1	5.5	9.7	25.2	11.3	29.3
Shrub/Bushes	2.4	6.3	3	7.9	12	31.2	1.4	3.7
Plantation	0	0	22.6	58.8	0	0	0	0
Barren land	7	18.1	7.1	18.5	4.3	11.3	0.1	0.2
Cultivated land	28.1	73.2	1.4	3.4	1.6	4.1	4.3	11
Sand	0.2	0.4	1.5	3.9	1.5	3.9	0.7	1.9
Waterbodies	0.8	2	0.8	2	0.8	2	0.7	1.9
Total	38.5	100	38.5	100	38.5	100	38.5	100

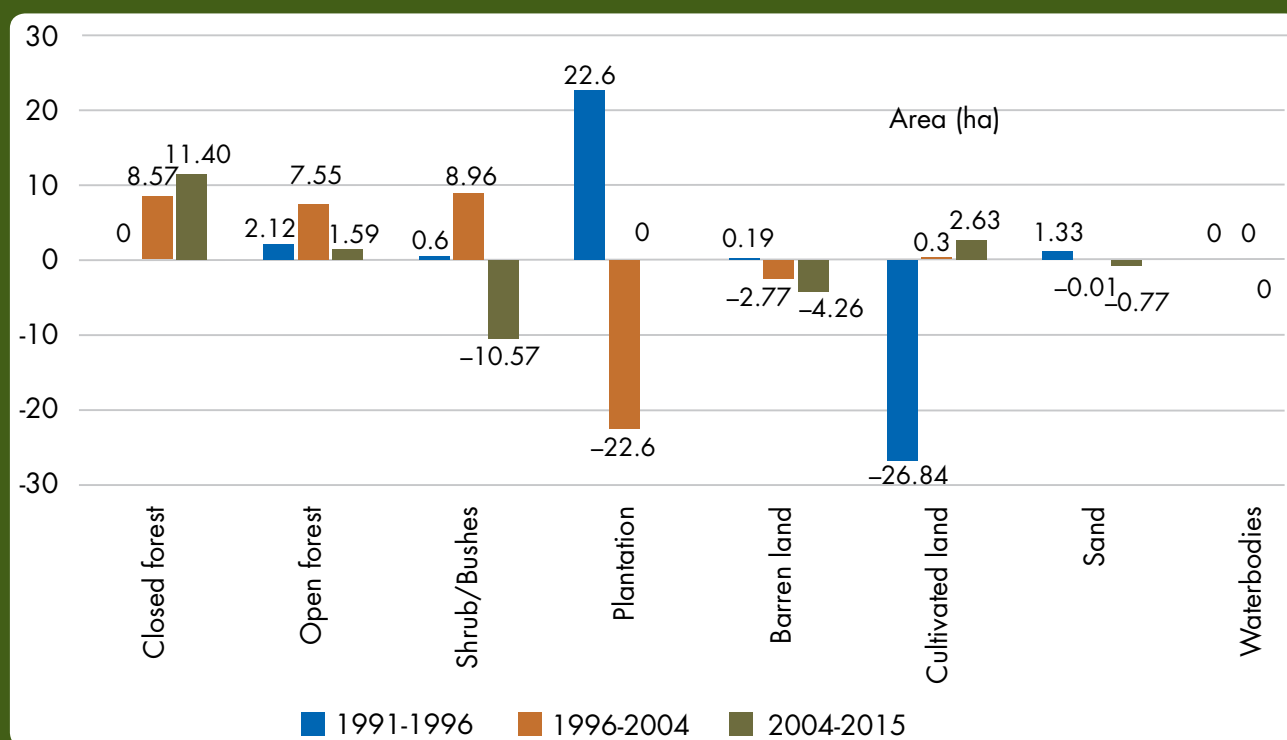
Figure 7: Land cover and land use maps (a) 1991, (b) 1996, (c) 2004, and (d) 2015



Land Cover and Land Use Change Analysis

The land cover and land use change analysis was performed in three different time periods: 1991-1996, 1996-2004, and 2004-2015. The plantation was started in 1996, and serves as evidence for no close forest during 1991-1996. The situation changed progressively in the ensuing time periods. As the plantation was established with fast-growing species, open canopy forest developed in some places during the first three-year period, increased significantly during 1996-2004, and then increased slightly in the most recent decade. The increase in the area of open forest can be attributed to the early successional period, while the period of slight increase indicates maturity of the forest.

Figure 8: Land cover and land use change comparison of 1991-96, 1996-2004, and 2004-15

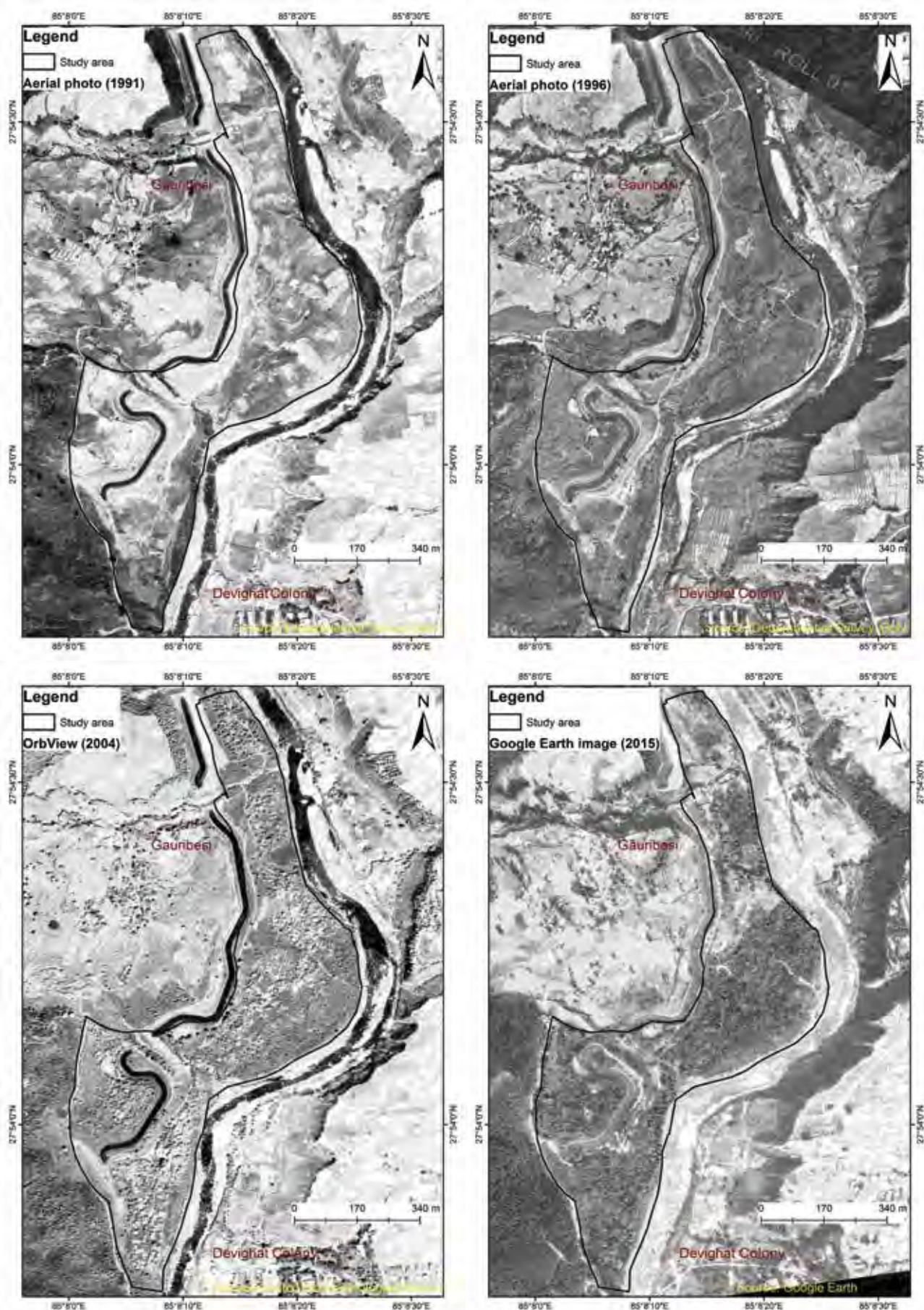


Visual Interpretation of Aerial Photographs and Satellite Images

The Plantec coffee agroforestry was established on land belonging to Devighat Hydropower, which construction was beginning in from 1984. According to the information provided by the company, the land was partially cultivated by the local community before 1994. This was confirmed by the texture, tone, and shape of the land in aerial photos from 1991, which depict barren land along the left bank of the headrace channel of Devighat Hydropower and the distinctive level terraces of cultivated fields. Similarly, the black portion visible in the southernmost part of the image along the right bank of the Trishuli and next to the road indicates coverage of shrubs/bushes. Immediately after Plantec leased the land, they started the plantation of shaded trees as well as coffee (*Coffea Arabica*). The plantation was started from the northern section of the estate, which is visible in aerial photographs of 1996 as in Figure 9. Primarily, nitrogen-fixing plants were planted to increase soil fertility and moisture. Other planted tree species were *Dalbergiasisso*, *Leucaenaleucocephala*, *Micheliachampaca*, and *Jacaranda mimosifolia*. Plantation of trees was carried out on a large scale, maintaining a distance of 20-25 feet between trees and five feet between coffee plants.

During the plantation phase (1994 onward), Plantec built their own nursery and prepared the managed drain system throughout the planted area. Continuous maintenance and replantation were performed in order to grow enough

Figure 9: Comparative map of 1991, 1996, 2004 and 2015 for forest cover change



shaded trees. This resulted in gradual conversion of non-forested land to forest-like structure. Spatial signatures such as color, texture, tone, pattern, and other associated information on the Orbview image (2004) offered evidence of the early succession stage of the forest. Unpacked and pointed canopy with unevenly distributed shape also confirmed the situation during 2004 (Figure 9). During the most recent decade (2004-2015), the area was covered with trees with well-structured canopy. At present, the owner of estate is planting grass on the river bank, which on one hand protects the bank and on the other hand provides green manure for the coffee fields.

Zoom-in visualization can be used as data exploration tool for investigating relationships and drawing conclusions regarding the nature of changing forest cover. An increase in vegetation coverage was visible during 1991-1996 (Figures 10a & 10b). The situation during 1996-2004 was different: forest cover had increased north of the suspension bridge, but had decreased around the bridge (Figure 10c). This is explained by encroachment on the land by the local community during 2004-2005, when the Maoist insurgency was at its peak. As a consequence, some of the land in this area was re-converted to cultivated land, as reflected in Figure 10d.

As with the northern part, stages of forest development are clearly visible across the southern part of the study area (Figure 11). During 1996-2004, a fraction of sunlit background of the area was decreased, with an increase in tree size and density. After 20 years of agroforestry, forest with well-established canopy was observed in the latest image (Figure 11d).

Benefit sharing

The main rationale for the private sector to invest in developing an agroforestry system consisting of shaded coffee is to generate profits. Today the Plantec Coffee Estate (P) Ltd. stands out as the largest coffee estate in the country and also as an exporter of premium organic coffee. While generating income from coffee, it also generates employment on the estate for all the plantation management-related activities. Employment opportunities are rare in this area and the plantation hires local labour, generally women who are illiterate, on a daily basis for conducting activities such as application of manure, weeding, thinning, picking, and processing the beans. Plantec employs a separate group of people in Kathmandu who carry out the roasting and packaging of the finished coffee product. This way, while restoring the 38.5 ha of degraded landscape, both the company and the local population benefit from the economic opportunity created by the company.

Discussion

This study was designed to assess the land cover and land use changes and carbon stocks of the Plantec Coffee Estate (P) Ltd. field site (study area). Both qualitative and quantitative analysis were performed in order to acquire temporal land cover and land use change data. Use of aerial photos, high resolution satellite images, and Google Earth images helped to illustrate the extract situation supported by field visits. Aerial photos of 1991 and 1996 were used to reflect the situation in the respective years because they are a valuable source of historical information on vegetation cover and condition (Carmel & Kadmon, 1998; Erikson, 2003) In Nepal, a study conducted by Balla et al., (2003) advised the use of aerial photographs from the Department of Survey to accurately assess land cover of that period.

An OrbView image of one meter resolution was used to illustrate the forest condition in 2004 because it was found to be effective in topographic mapping and could be used for extracting small features of the forest (He et al., 2009).

Similarly, a Google Earth image was used to illustrate the forest cover change and to digitize the land cover in 2015, as it was believed to produce more accuracy than other medium-resolution images such as Landsat products (Ghorbani & Pakravan, 2013). Intensification of vegetation was also clearly visible in field photographs taken in 1995 and 2016, which were used to compare the past and present land use of an area (Figures 12 and 13). Such matched field photographs are regarded as an important tool to examine and understand temporal change in both surficial physical and biological processes of an area (Bierman et al., 2005). Integrating repeated photography with satellite image analysis with community interviews was considered an appropriate method for landscape change analysis (Niraula et al., 2013).

Figure 10: Comparative map of (a) 1991, (b) 1996, (c) 2004, and (d) 2015, assessing the forest cover change of northern portion of study area

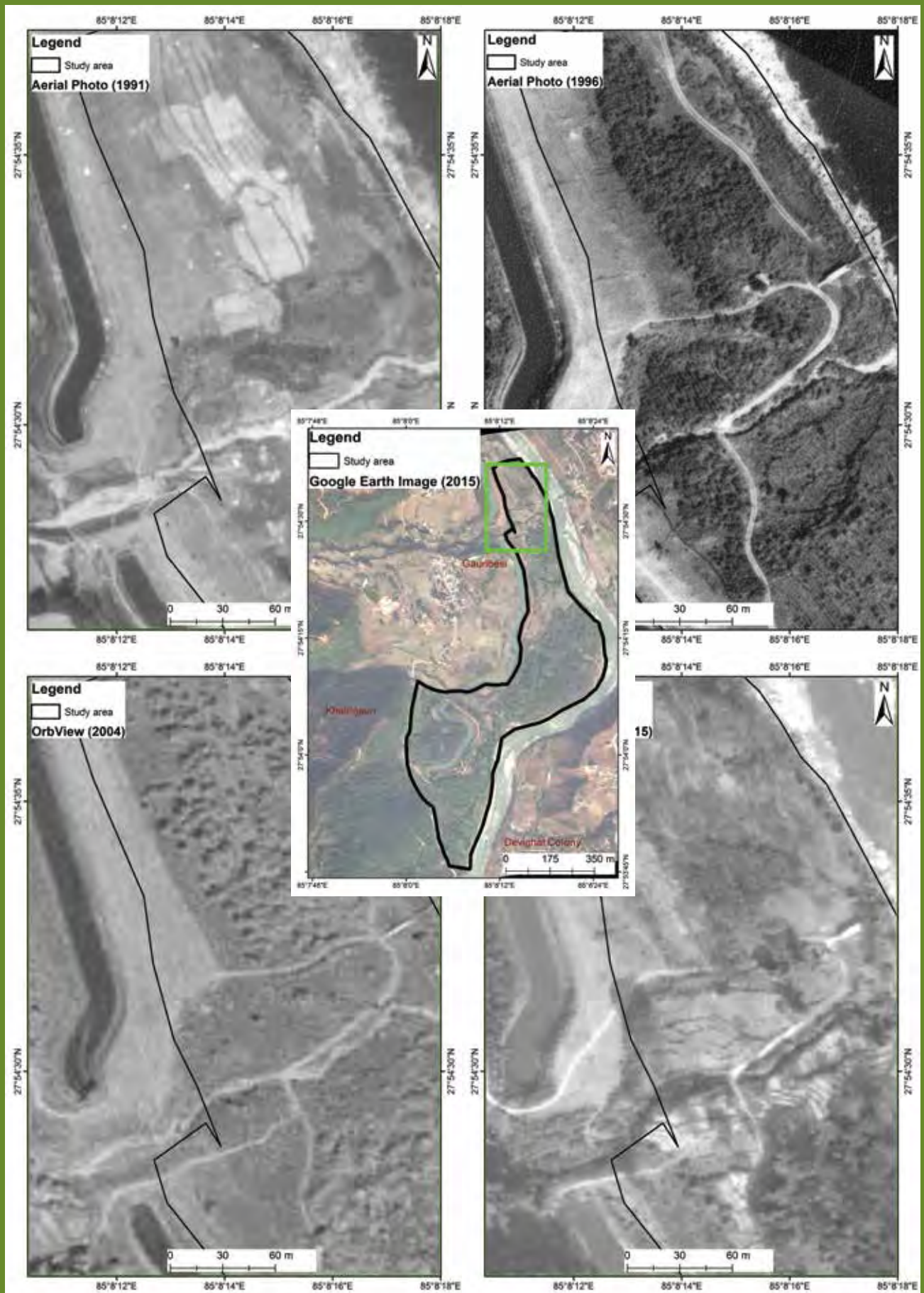


Figure 11: Comparative map of (a) 1991, (b) 1996, (c) 2004, and (d) 2015, assessing the forest cover change of southern portion of the study area

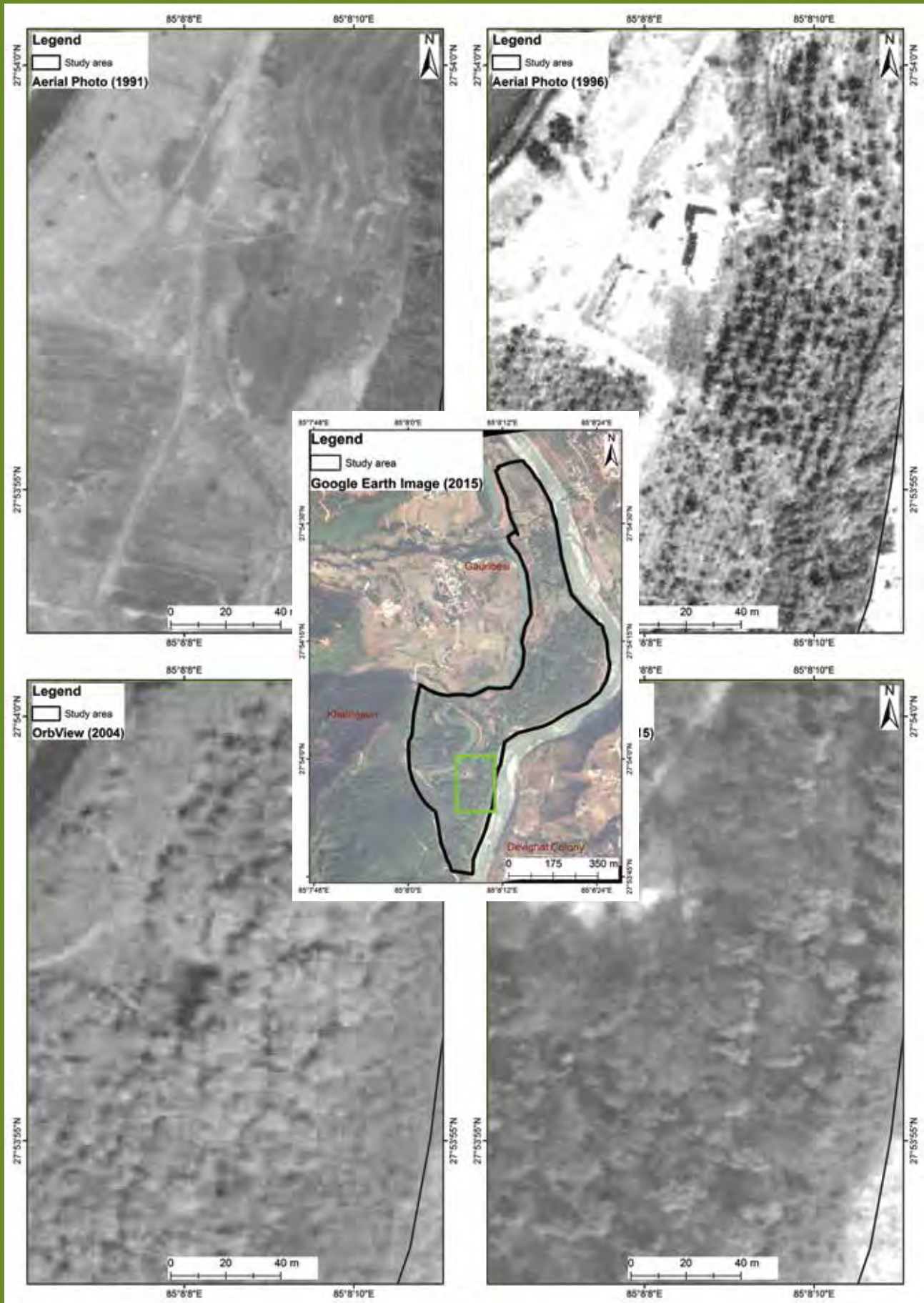


Figure 12: **Plantec Coffee Estate**



Photo point: Lat. 27.8961° and Long. 85.1348° (Above: 1995. Below: 2016)

Figure 13: **Plantec Coffee Estate**

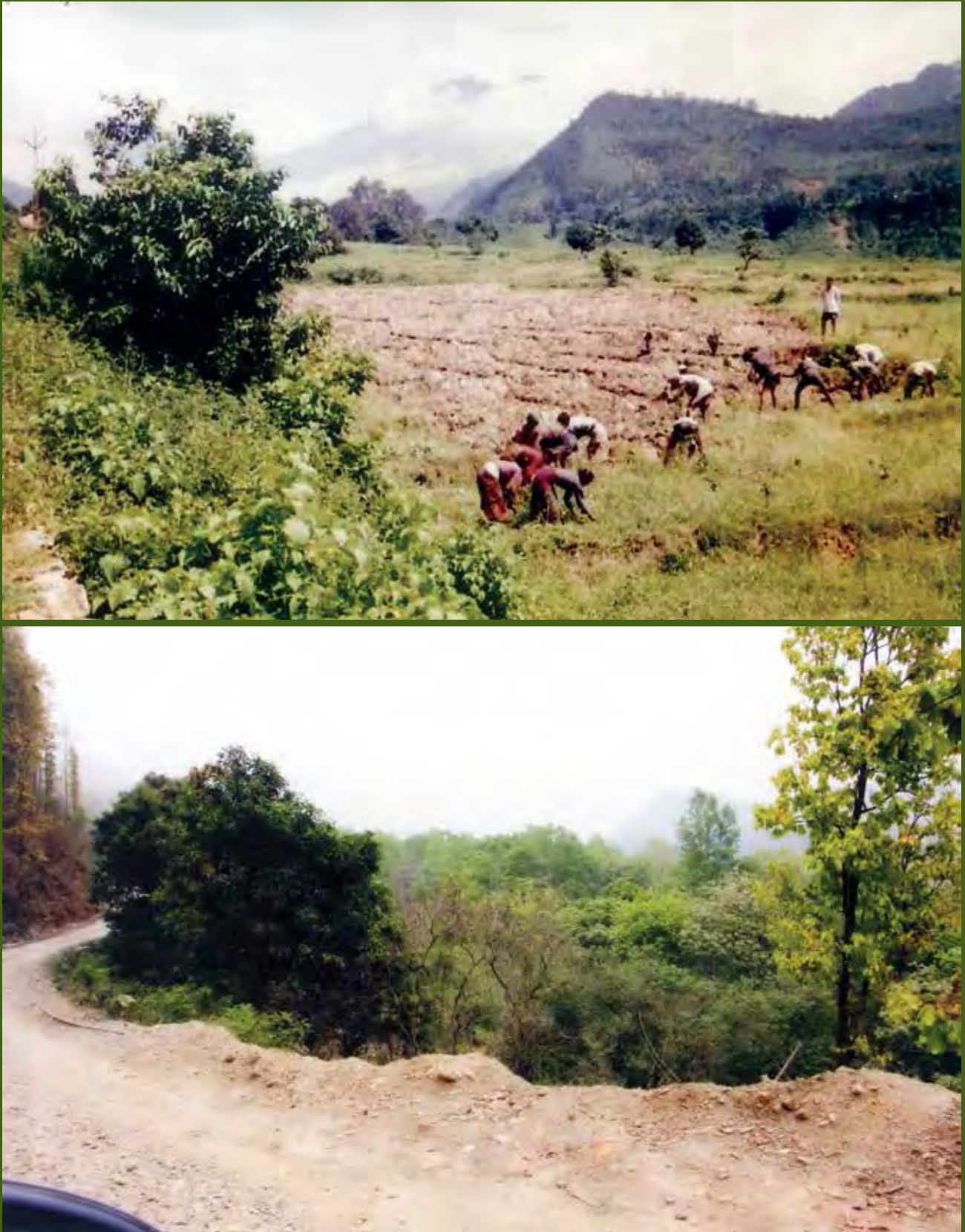


Photo point: Lat. 27.8961° and Long. 85.1348° (Above: 1995. Below: 2016)

Carbon assessment

Results showed that 54.3% and 32.7% of total carbon stock in the Plantec Coffee Estate were contributed by above-ground tree carbon and soil organic carbon, respectively. This indicates that tree components and soil organic matters play a crucial role in shaded-grown coffee agroforestry. The average above-ground tree carbon (95.9 tC/ha or 351.95 tCO₂/ha) in the coffee agrosystem of Plantec Coffee Estate resembled the finding of Kandel, (2015), who reported the value of 97.5 tC/ha for the Tarai arc landscape forest of Nepal. However, the average above-ground carbon stock was found to be 103.2 tC/ha, which was greater than Laxmi Mahila CF (50.4 tC/ha) and lower than Jalbiri Mahila CF (128.83 tC/ha) in the Gorkha district (Neupane & Sharma, 2014).

In the same way, the average soil organic carbon on the Plantec Coffee Estate was found to be 57.8 tC/ha (212.13 tCO₂/ha), which is similar to the national middle mountain average (54.3 tC/ha), as reported by DFRS (2015). Also, this finding is closer to the Collaborative forest of the Mahottari district, where the SOC range is 61.3-66.3 tC/ha (Mandal et al., 2012) and the Pokhare Khola sub-watershed of Dhading, which shows SOC as 51.5 tC/ha (Pradhan et al., 2012). The SOC value is higher than the Leasehold forest of Kayer Khola (21.3 tC/ha) and the Betrawati watershed (40.7 tC/ha), studied by Bajracharya et al., (2016).

In addition, the total average carbon stock (176.5 tC/ha or 647.76 tCO₂/ha) was higher than the national middle mountain average (138.1 tC/ha), as estimated by the DFRS/FRA (2015) and the forest Pokhare khola sub-watershed of Dhading, studied by Pradhan et al., (2012). But the value is lower as compared to CFM (197.1-274.6 tC/ha) studied by Mandal et al. (2012) and the protected forest (274.5 tC/ha) from the Tal area studied by Manandhar, (2010). The average total carbon stock value is low as compared to the results of the dense forest (298.0 tC/ha) and sparse forest (257.3 tC/ha) of Kayer Khola (ANSAB et al. 2012). The same study found that the mean carbon stock in the Charnawati watershed varies from 168.2 tC/ha in sparse forest to 231.3 tC/ha in dense forest, and that for Ludhikhola it varies from 167.0 and 221.8 tC/ha in sparse and dense strata, respectively. Although comparing the carbon stock in different land use and forest management areas is very difficult due to the multiple variables involved (even plots in the same management regime with the same region and similar tree species composition can vary in their storage capacity, depending upon micro topographic, climate, soil types, etc.), current study has revealed that the Plantec Estate has been progressively doing better on carbon storage.

Total carbon stock in Nepal was estimated as 1,157.4 million tons (DFRS/FRA, 2015). Recently, the National Forestry Sector Strategy (2016-2025) aims to enhance Nepal's forest carbon stock by at least 5% by 2025, as compared to the 2015 level. In order to achieve this target, 57.9 million tons of additional carbon should be stocked. As shaded-grown coffee has already been recognized as a viable strategy for afforestation and reforestation under the Clean Development Mechanism (CDM), this kind of private agroforestry would be the better option for storing the carbon. Such agroforestry will possibly help to achieve the goals set on Agricultural Development Strategy, Nepal (2014), which emphasizes the promotion of tea and coffee cooperatives.

In this context, if somebody replicates the achievements of Plantec Coffee, which has stocked about 6,795 tons of carbon (equivalent to 24,939 tCO₂) in 38.5 ha in a 20-year period, this will contribute 0.01% of the national target. At USD 5 per tCO₂, the total value of carbon sequestered by this estate over a 20 year period would be approximately USD 124,693.

Under the assumption of uniform carbon stock (176.5 tC/ha) along the temporal and spatial coverage, the following scenario can be developed (Table 5):

There are two options to improve carbon storage through shaded-coffee farming: i) a higher number of individual farms, and ii) landscape-level farming. It is well-established that planted forest has advantages over natural forest, with higher annual productivity and potentiality for carbon storage and sequestration (Lal & Singh, 2000). Thus, creation of new forest-like structure on degraded, barren, or cultivated land is a better option for increasing carbon storage. This estate covers an area of just 38.5 ha and has had

Table 5: Carbon contribution scenario

Scenario of contribution	Carbon to be contributed (million tons)	Estimated number of farms with an area of 38.5 ha	Total area required (ha)
1%	0.6	85	3,273
2%	1.2	170	6,545
5%	2.9	426	16,401
10%	5.8	852	32,802

a major environmental impact by regaining land fertility, storing water, and conserving biodiversity, among other benefits. Moreover, the company is acknowledging their social responsibility by donating three-to-four tons of timber and firewood each year to nearby schools. These materials were produced during pruning activities on shade trees with the goal of removing broken branches and branches at lower heights (<3 m).

Conclusion

After the Paris Agreement 2015, INDC and REDD+ as global instruments have paved the way for financing landscape conservation and sustainable management. Conservation is already seeing a decrease in funding, and with these new incentive-based mechanisms, countries must demonstrate results in order to be paid, an approach commonly known as performance-based finance. To be able to demonstrate results, one needs investment first and to be paid once results are demonstrated and verified (ex-post). This calls for up-front project development costs (ex-ante cost) and thus there is a growing understanding that the role of the private sector is essential in order to make these investments.

This paper has shown how a private sector entity, Plantec Coffee Estate (P) Ltd., was able to successfully bring about a positive change in restoring degraded land through private investment over a 20-year period.

Though this restoration of degraded riverbank was done through private investment on land leased from the government for non-climatic purposes, twenty years later it serves as a perfect example of the role the private sector can play in climate mitigation and adaptation. Interventions like this, will be the key to assisting developing nations like Nepal in fulfilling their NDC commitments and meeting the REDD+ objectives of carbon enhancement and sequestration while simultaneously addressing social and environmental safeguards. The Plantec plantation has created employment opportunities which otherwise would not have existed. The restoration of the forest cover has produced a favourable habitat for birds and small mammals and created an important refuge at a time when forest fragmentation is making it difficult for wildlife to find suitable habitats.

The study attempted to develop an evidence-based history of the conversion of cultivated land to coffee agroforestry through aerial photographs, satellite images, and terrestrial photography. The total average carbon stocked by the forest was calculated to be 176.5 tC/ha (647.76 tCO₂).


The agroforestry system of shaded-coffee farming can become a suitable REDD+ activity to meet national carbon enhancement and sequestration goals. Simultaneously, it can contribute to income-generation opportunities for local communities through the creation of job opportunities at the plantation site, while contributing to environmental sustainability. This paper shows that the involvement of the private sector in agroforestry intervention can have triple dividends: restoration of degraded landscape, income generation opportunities at different levels, and contributions to environmental sustainability. This is a perfect model of a green economy.

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