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The Carbon Sequestration Potential of Community-based Forest Management in Nepal

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Abstract: A climate policy initiative called 'Reduced Emission from Deforestation and Forest Degradation and enhancement of forest carbon stock in developing countries (REDD+) is under consideration by the United Nations Framework Convention on Climate Change (UNFCCC). This policy is aimed at national level reduction of forest emissions in developing countries, as measured against an agreed upon national reference emission level. Net emission reductions would be credited and sold to an international fund or carbon market. It was conceived originally as a mechanism to encourage countries with high rates of deforestation, such as Brazil and Indonesia, to curb large scale deforestation due to agricultural expansion and timber extraction. But its potential has also been seen in terms of rewarding indigenous people and local communities for improved management of their forests such that biomass levels remain stable or increase. Since REDD+ is performance-based, the incentive for carbon services provided by such communities will be directly dependent on the annual carbon increment. This paper examines the carbon sequestration potential of community-based forest management in four community forests in Nepal. The four community forests (CFs) selected are from different watersheds in three physiographic regions. Forest carbon pools were measured in two successive years using the standard ground based inventory techniques. The measurements indicate that these CFs (with a total area of 630 ha) had a stock of approximately 478,000 tonnes CO_2e at the end of 2009, and through the CF practices, are able to sequester an additional 4700 tCO_2e every year. Furthermore, it assesses different management practices that could affect the carbon sequestration.

Keywords: Deforestation, Forest Degradation, Biomass Pools, Carbon Sequestration, Community Forestry, Well-being

Introduction

FORESTS COVER 31% of the world's surface area, and more than 22% of the total forest area is owned and/or managed by indigenous people and local communities (White and Martin, 2002). In a number of developing countries, such as Nepal, community forest management (CFM) schemes have been promulgated with the prime objective of protecting forests and supporting the livelihoods of local people, particularly the daily needs for fuel wood, fodder, timber and certain non-timber forest products. Nepal's CFM programme is very successful and an often considered a model example of

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CFM (Springate-Baginski and Blaikie, 2007). Nearly 25% of the country's forests have been handed over to more than 15,000 community forest user groups (CFUGs), involving one third of the total population of the country (DoF, 2011). Since the community forestry policy was initiated in Nepal in the 1980s, it has been shown to have significant positive impacts on forest condition and communities' access to forest resources (Springate-Baginski *et al*., 2003), with positive changes in environmental services such as biodiversity conservation, carbon sequestration and water source protection (Mikkola, 2002). So far, community forests are being managed by the local communities for better supply of forest products, and there has been no payment for the environmental services which are generated. Despite generally positive impacts, several studies have reported that current CFM benefits to the local communities are not sufficient to improve the well-being of many poor, marginalised and women-headed households (Pokharel and Carter, 2007).

A recent policy initiative called 'Reduced Emissions from Deforestation and Forest Degradation' (REDD+) is under consideration by United Nations Framework Convention on Climate Change (UNFCCC). This policy is aimed at national level reduction of forest emissions in developing countries, as measured against an agreed national reference emission level. Net emission reductions would be credited and sold to an international fund or carbon market. It was conceived originally as a mechanism to encourage countries with high rates of deforestation, such as Brazil and Indonesia, to curb large scale deforestation due to agricultural expansion and timber extraction, but its potential has also been seen in terms of rewarding indigenous people and local communities for improved management of their forests such that biomass levels remain stable or increase.

For example, in Nepal, the Norwegian Agency for Development Cooperation (NORAD) has provided finance for a pilot project in which the possibility of developing REDD+ activities based on existing CFM practices is being explored. The primary intended impact on forest stock of such practices is reversal of degradation and the enhancement of biomass within the forest. Hence the potential of REDD+ as an instrument in Nepal depends on the level of stock increases typically brought about by community management.

Very few studies have been carried out so far on the carbon dynamics of community forests. Karky (2008) conducted a forest carbon inventory in three community forests of Nepal, but the limited carbon inventory data, though indicative, do not represent the whole of Nepal's community forestry as carbon stock. Growth varies with factors such as climatic conditions, soil type, landscape and aspect, altitude, species and diversity, forest age and management practices, and more studies are needed to get a better idea of typical growth rates in community managed forests.

This paper examines the effectiveness of CFM in terms of carbon sequestration in three different physiographic regions: the low land (Terai), the mid-hills and the mountain areas of central Nepal.

Methodology

Study Area

In this study, four watersheds (Kayarkhola in Chitwan, Ludhikhola in Gorkha, Kulekhani in Makwanpur and Charnawati in Dolakha) were selected as research sites (Fig 1), to represent the three major physiographic regions of central Nepal. Since most CFM is carried out in the mid-hills, two watersheds (Ludhikhola and Kulekhani) were selected from this region and one watershed each from Terai and Mountain zones. Discussions and meetings were held with the potential and interested forest user groups (FUGs) (at least 3 FUGs in each watershed) and stakeholders, before four FUGs (one from each watershed) were chosen (Pragati in Chitwan, Borrow Pit in Makwanpur, Ludidamgadhe in Gorkha and Thansa Deurali in Dolakha).

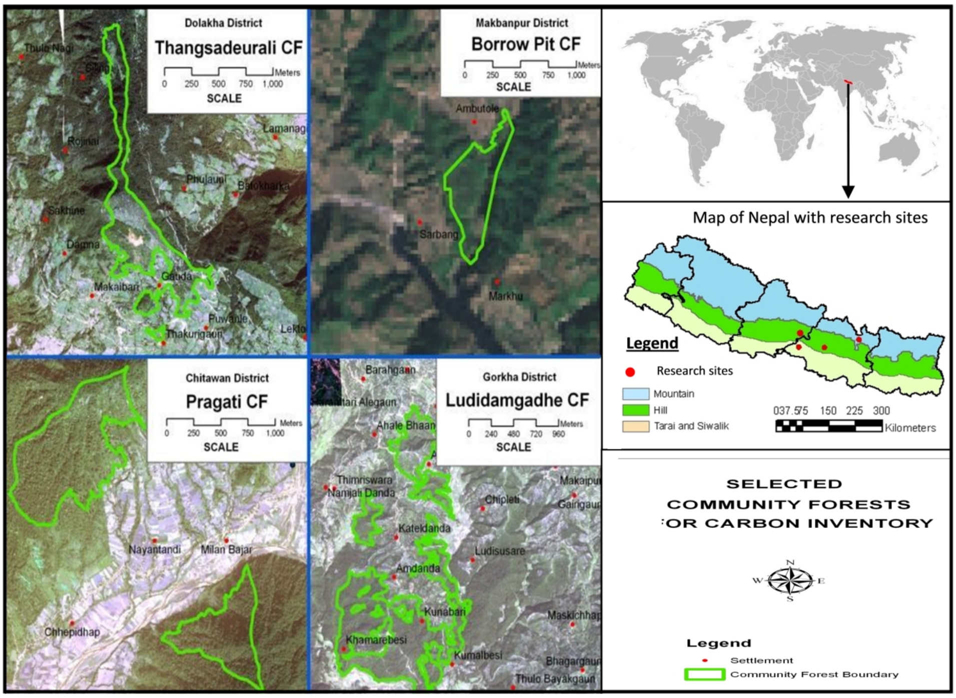


Figure 1: Map Showing Three Physiographic Regions of Nepal with Location and Boundary of Selected Community Forests and Settlements (Data Source: ICIMOD, 2010)

In selecting these FUGs, priority was given to those with more forest dependent people, particularly FUGs with poor, marginalised indigenous people and women members, since this is the target beneficiary group in Nepal for REDD+. General information about the research sites is provided in Table 1.

The forests concerned were handed over to the local community during the 1990s, when they were badly degraded due to excessive use of forest resources, over grazing and illegal logging activities. As table 1 shows, there are significant differences in the dominant tree species and in the sizes of these forests. Moreover, the income currently gained varies greatly. This is because selling timber is a major source of income in Chitwan, Gorkha and Dolakha but Makwanpur CFUG does not normally cut trees as their forest is too small. In particular Pragati CF in Chitwan has some very mature trees, sales of which generate significant income.

Table 1: Description of the Field Study Sites

Research site	**Chitwan District (Terai)**	**Makwapur District (Mid-hills)**	**Gorkha District (Mid-hills)**	**Dolakha District (Mountain)**
Watershed	Kayarkhola	Kulekhani	Ludikhola	Charnawati
Name of community forest	Pragati	Borrow Pit	Ludi Damgade	Thanksa Deurali
Altitude (App. amsl)	100–300 m	1200–1700 m	500–1200 m	2100–2300 m
Date CF registered	1994	1996	1994	1992
Area of CF (ha)	145	26	241.15	217.1
Households	153	73	515	384
Annual forest income in 2010 (US$)	22500	105	5320	1430
Dominant tree species	*Shorea robusta Lagerestroemia parviflora*	*Pinus wallichiana Alnus nepalensis*	*Pinus roxburghii Schima wallichii*	*Pinus petula Pinus wallichiana*
Main castes	Chepang, Newar, Kami (Black smith)	Tamang, Newar	Brhamin, Chhetri, untouchable caste	Chhetri, Newar, untouchable caste
VDC/Municipality	Shaktikhor VDC	Markhu VDC	Gorkha Municipality	Bhimeshwar Municipality
Rainfall (mm)*	1436	2125	2000	2232
Ecological zone	Tropical and sub-tropical	Sub-tropical	Sub-tropical	Temperate
Source: Field survey, 2010				

Forest Carbon Inventory

There are two major approaches for estimating the change in forest carbon stock: gain-loss and stock difference approaches (IPCC, 2006). The stock difference approach was used in this study as this is a more reliable, easy and cost-effective method for estimating the changes in forest carbon stock over a given time period in different pools. The first round data collection was carried out in November and December 2009 and second round data in the same months the following year.

Several methods can be used to measure the changes in forest carbon stock. The Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidance provides general procedures, while the Voluntary Carbon Standard (VCS), Winrock International sourcebook, the Climate, Community and Biodiversity Alliance (CCBA) all give detailed protocols for use at local level, as do Pearson *et al.* (2007), Chave *et al*. (2005) and MacDicken (1997).

The plot method (ground based inventory) was used in this research because it is very simple and easy to apply, suitable for long run monitoring and cost effective (Ravindranath and Ostwald, 2008). The protocol applied in this study is based on the IPCC guidelines and the Community Forestry Inventory Guidelines prepared by the Forest Department of Nepal, combined with the step by step procedure developed by MacDicken (1997).

Forest inventory training was provided to the selected members of the FUGs in the study areas. Refresher training was organised in the second year to remind them of the process and data recoding techniques.

Boundary Mapping and Stratification

A participatory map of each community forest was prepared with the help of local people as they are very familiar with important characteristics of the forest such as species distribution, age class and crown density. The boundary of the community forest was mapped jointly by the researcher and community members, using GPS and ArcGIS. For this, the entire forest boundary was visited and coordinates marked.

In order to increase the accuracy of carbon measurement, the forests were divided into two major strata: sparse (less than 70% crown canopy) and dense (more than 70% crown canopy) using ArcGIS software with high resolution remote sensing image, ERDAS Imagine and Definiens Developers.

In each forest except Makwanpur (which is very small), a block of forest (around 5 ha) was selected to represent the biomass of whole forest (this was necessary because of time and resource limitations). For each selected forest, variance analysis was carried out to determine the number of permanent plots needed to achieve a confidence level of 90%, as explained below.

Variance Estimation for Sampling Intensity

Ten to fifteen temporary plots of 5.64 m radius (an area of 100 m^2) were randomly selected in all sites. Diameter at breast height (DBH at 1.3 m) of all trees equal to and greater than 5 cm was measured to determine variance in tree stocking. All research sites in this study have a moist climate with annual rainfall between 1500 and 4000 mm, so the equation suggested by (Brown *et al*., 1989) was employed.

$$Tree\,Biomass\,(kg) = 38.4908 - 11.7883 * DBH + 1.1926 * DBH^2$$

Biomass of the temporary plots was converted into carbon by multiplying by 0.47 (IPCC, 2006) and the mean tree carbon per hectare was estimated. The total number of permanent plots required was calculated using the following statistics (MacDicken, 1997) and the number of permanent plots is listed in the table 2.

$$N = \frac{(CV * t)^2}{E^2}$$

Where

N = Maximum number of sample plots
CV = Coefficient of variation of biomass
t = Value of t obtained from the student's t-distribution table at n-1 degrees of freedom of the pilot study, at 10% probability
E = Sampling error at 10%

Table 2: The Required Number of Permanent Sampling Plots

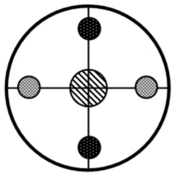
Name of CF	**Total forest area (ha)**	**Area of the forest/ selected block (ha)**	**Mean tree carbon stock (t ha ^{1})**	**Standard Deviation**	**No. of pilot sample plots**	**Required sample plots**	**Sample plots added**	**Total sample plots**
Chitwan	137	11	102.4	27.6	12	5	2	7
Makwanpur	27	27	66.8	21.4	15	6	2	8
Gorkha	241.5	5	110.5	35.2	10	6	2	8
Dolakha	217.5	9	87	23.9	12	5	2	7
Total	623	52			49	22	8	30

Distribution of Permanent Sampling Plots

The analysis results show that a total of 22 permanent plots would be required across the four CFs, however 8 more plots were added (2 plots in each research site) to enhance the reliability of the results (Table 2). Circular plots were used because they are easier to establish and it is less problematic to determine whether trees are inside or outside than in rectangular plots. Hawth's ArcGIS analysis tool was employed to distribute the plots randomly across the forests, and the coordinates of the plot centres were loaded into the GPS (Garmin Map 60CSx). The centre of the plot was marked in the field using a wooden peg.

Circular plots of 5.64 m radius were used to measure the above ground tree biomass, with a 1 m radius nested plot for sapling biomass at the centre (Box 1). For leaf litter, grass and herb biomass, 0.56 cm radius plots were established between the centre and north edge for the first year and between the plot centre and south edge for the second year. For soil carbon estimation, soil samples were collected from pits at 30 cm depth between the plot centre and east or west edge of the plot.

Box 1: Circular plot design



● 0.56 cm radius for leaf litter and grass biomass

◍ 30 cm depth soil pit for soil sample collection

▨ 1 m radius species and seedling counting, and sapling biomass

○ 5.64 m radius for tree and sapling biomass

Pool-wise Carbon Inventory

Five different carbon pools: above ground tree biomass, below ground tree biomass, above ground sapling biomass, leaf litter, grass and herb biomass and soil carbon were measured to estimate the total forest carbon stock and annual changes. The process and methods used in the study are described below.

Above-ground Tree Biomass (AGTB)

All trees equal to or above 5 cm DBH were measured for diameter and height using a DBH tape and clinometers (Photo plate 1). Data on each measurement were recorded in a spreadsheet and a simplified standard regression model based on DBH, height and wood density was used to calculate the biomass of the trees as suggested by Chave *et al*. (2005, p. 93). A number of regression models have been developed to estimate Nepalese forest biomass, however, these models are based on small number of harvested trees and do not represent the tree of higher diameter class, and they are available only for few species. On the other hand, the Chave group considers wood specific gravity of each plant species, one of the important variables in the biomass function. This model was also tested with five other models in Utter Predesh in India, similar climatic condition and vegetation types with Nepal. They found more accurate results from this model than others so the Chave *et al*. (2005) regression model was used for this study.

$$AGTB = 0.0509 * \rho D^2 H$$

Where

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

Photo Plate 1: Tree Inventory-Measuring Tree Diameter and Height in the Research Sites

Above-ground Sapling Biomass (AGSB)

Saplings with diameter between 1 and 5 cm were measured at 1.3 m height. AGSB was analysed by using a site and species specific national allometric regression model, which was developed jointly by the Department of Forest Research and Survey, Tree Improvement and Silviculture Component, and the Department of Forest, Nepal (Tamrakar, 2000).

$$Log(AGSB) = a + b\log(D)$$

Where

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

Leaf Litter, Grass and Herb (LGH)

Destructive sampling was applied to estimate the biomass of this vegetation category. The forest floor litter materials (dead leaves, twigs, fruits and flowers) from 1 m^2 area were collected, avoiding contamination with soil and stones (Photo plate 2). The live components, mainly grass and herb, were also harvested and weighed. Samples of these collected materials were then taken to a lab at Institute of Engineering, Tribhuvan University, Pulchowk and oven dried at 105 degree Celsius until they reached a constant weight. The samples were used to extrapolate leaf litter, grass and herb (LGH) biomass per hectare by using the following formula, and carbon content was determined by multiplying with IPCC (2006) default carbon fraction of 0.47.

$$LHG = \frac{W_{field}}{A} \cdot \frac{W_{subsampledry}}{W_{subsamplewet}} * 10$$

Where,

LHG = biomass of Litter, Grass and Herb (t ha-1)
W_{Field} = weight of the fresh field sample, destructively sampled within an area of size A (kg)
A = size of the sample collection area (m2)
$W_{\text{subsample dry}}$ = weight of the oven-dry sub-sample taken to estimate moisture content (g) and
$W_{\text{subsample wet}}$ = weight of the fresh sub-sample taken to estimate the moisture content [g]

Photo Plate 2: Leaf Litter Collection

Below-ground Tree Biomass (BGTB)

Methods for estimating below ground biomass (biomass of the roots) for different land use systems are still not standardized (IPCC, 2006). Excavation of roots, root to shoot ratio and allometric equations are the commonly used methods to estimate this pool. Destructive excavation is however very complex, time consuming and expensive (MacDicken, 1997), whereas the available allometric equations are not suitable for this study as they are mostly based on the native forests (Ravindranath and Ostwald, 2008), while the forests in our research sites are mixed of natural and plantation types. Therefore, the conservative root to shoot ratio value was used to calculate the root biomass. As most of the research sites are similar to tropical moist deciduous and sub-tropical humid forests a 0.20 fraction was used to estimate the below ground carbon as IPCC (2006) and MacDicken (1997 p. 14) recommend.

Soil Organic Carbon

Soil organic carbon is an important carbon pool as it contains 81% of the total carbon of the terrestrial ecosystems (WBGU, 1998). The soil carbon stock in the forests may vary substantially: from 54% to 84% of the total carbon (Bolin *et al.*, 2000). Despite its significant influence in determining the overall amount of carbon at a landscape level, the study however did not measure soil carbon increment directly in the field, not because of limited time and laboratory resources, but also because it was assumed that levels of soil organic carbon would not change between the first year and the second year measurements, given that no losses were expected and annual increments would be very slow.

Soil carbon data were obtained from ICIMOD (2010) to calculate the baseline forest soil carbon. Soil sample was gathered during 2010 (Photo plate 3) from all research sites (except Makwanpur) and analysed by using the following equation:

$$SOC = \rho \times d \times \%C$$

Where

SOC = soil organic carbon stock per unit area (t ha-1)
ρ = soil bulk density (g cm-3)
d = the total depth (30 cm) over which the sample was taken, and
$\%C$ = carbon concentration in percentage

Plate 3: Soil Sample Collection (Source: ICIMOD, 2010)

Total Carbon

Forest biomass of all pools was converted into forest carbon by multiplying by the default value 0.47 (IPCC, 2006). Carbon was summed, and the total was then multiplied by 44/12 in order to convert to carbon dioxide equivalent. Then first year total carbon was deducted from the second year carbon to estimate the annual increment.

Results

Stand Characteristics

From the 30 permanent plots established in four research sites, altogether 17 tree species were recorded. The greatest diversity of species (12) was found in Chitwan, followed by 3 each in Gorkha and Makwanpur and 2 in Dolakha (Table 3). *Shorea robusta*, *Pinus roxburghii*, *Pinus wallichiana and Pinus petula* are the dominant tree species in Chitwan, Gorkha, Makwanpur and Dolakha respectively, whereas *Pinus wallichiana* was also found in Dolakha's forest. More species diversity was observed in Chitwan because it is a purely natural broadleaf forest promoted through natural regeneration. The rest are pine forests, established through enrichment plantation and community protection. The tree density per hectare was also highest in Chitwan (1457) compared to other sites, as forests are younger at Chitwan. Average stand height was lowest in Chitwan (7.5 m). The mean basal area per ha was greatest in Gorkha (27.84 m^2/ha).

Table 3: Stand Characteristics

Location	**Chitwan**	**Gorkha**	**Kulekhani**	**Dolakha**
No of tree species	12	3	3	2
Age of the stand	10	25	17	25
Average tree height (m)	7.52	16.16	14.99	14.18
Density (tree/ha)	1457	725	900	350
Basal area (m^2/ha)	22.58	27.84	21.24	19.34

The data shows that all four community forests were relatively young. The average DBH and height were only 16.3 and 12.4 m respectively. Nearly 98% trees were below 30 cm DBH and 68% were less than 20 cm DBH, and height of nearly 95% of the trees are less than 20 m (Fig 2). This is because these forests had been handed over for local community management after 1990, before which they had been badly degraded.

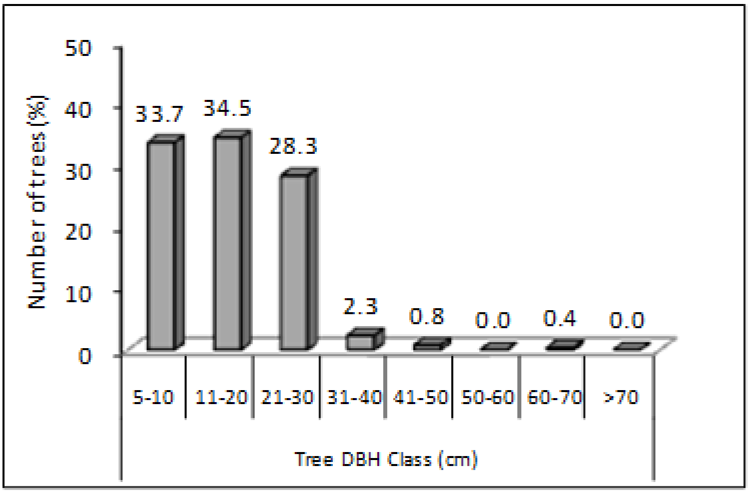


Figure 2a: Number of Trees in Different DBH Class in all Sites

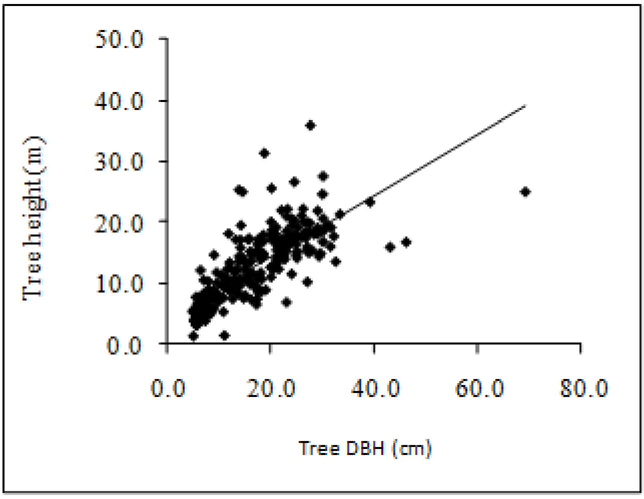


Figure 2b: DBH and Tree Height of Trees in all Sites

More than 80% of the trees in the Chitwan forest and 72% of the trees in Kulekhani belonged to the 5–10 and 11–20 cm DBH classes, respectively. Similarly, more than 78% of the trees in Gorkha and 53% of the trees in Dolakha were in the 21–30 DBH class (Table 4).

Table 4: Number of Trees in Different DBH Class (%)

Location	Number of trees (%) in different DBH Class (cm)							
	5–10	11–20	21–30	31–40	41–50	50–60	60–70	>70
Chitwan	80.4	10.8	3.9	2.0	2.0	0.0	1.0	0.0
Gorkha	3.6	39.3	53.6	3.6	0.0	0.0	0.0	0.0
Kulekhani	4.2	72.2	23.6	0.0	0.0	0.0	0.0	0.0
Dolakha	0.0	14.3	78.6	7.1	0.0	0.0	0.0	0.0

According to the literature the rotation period of *Shorea robusta*, the dominant species in Chitwan, is more than 100 years and individuals can reach an average height of 50 m with maximum 5 m DBH (ICRAF). *Pinus roxburghii*, *Pinus wallichiana and Pinus petula*, the dominant species of Gorkha, Kulekhani and Dolakha respectively, can live more than 100 years, reach up to 2 m DBH and attain more than 50 m in height (ICRAF). Although tree growth varies with climatic, edaphic and plant factors, there is apparently good opportunity to sequester atmospheric CO_2 and enhance the forest biomass for at least several decades in forests with these species in the CFs of this study.

Baseline Forest Biomass and Carbon

The first year carbon inventory results are shown in the Table 5. The biomass carbon (C) was highest in Gorkha (115.4 t ha^{-1}), followed by Chitwan (96.1 t ha^{-1}), Dolakha (91.7 t ha^{-1}) and Makwanpur CF (58.9 t ha^{-1}) (Table 5). However, the soil carbon was highest in Chitwan and the lowest in Gorkha.

Table 5: Summary of First Year Forest Biomass Inventory

Locations	Biomass in different pool (t ha-1)					Total Bio-mass	Total Bio-mass Carbon	Soil Car-bon	Total Forest Carbon	CO2 Equival-ent
	AGTB	BGTB	AGSB	GHB*	LLB**		t ha^{-1}			
Makwan-pur	102.2	20.4	0	0.3	2.3	125.2	58.9	119.3	178.2	654
Gorkha	199.7	39.9	0	0.5	5.3	245.4	115.4	106.6	222.0	815
Gorkha	199.7	39.9	0	0.5	5.3	245.4	115.4	106.6	222.0	815
Chitwan	162.9	32.6	3.7	0.4	4.8	204.4	96.1	119.3	215.4	790
Dolakha	158.5	31.7	0	0.6	4.4	195.2	91.7	119.4	211.1	775
Dolakha	158.5	31.7	0	0.6	4.4	195.2	91.7	119.4	211.1	775
Average	155.8	31.2	0.9	0.45	4.2	192.6	90.5	117.8	206.7	759
* Grass and herbs biomass, and ** Leaf litter biomass										

The variation in biomass carbon in different locations was mainly due to the forest age and the distance of the population settlement to the forest. Ludidamgade CF in Gorkha started at least 5 years before the others. The below ground C obviously followed the same trend, as it was estimated using a 0.2 fraction of above ground biomass. Saplings were present only in Pragati CF (1.75 t ha^{-1}), because other forests were pine dominated plantation forests with very little regeneration. The highest GHB was recorded at Dolakha whereas both GHB and LB were lowest in Makwanpur. The distance to the forests is greater in Dolakha compared to other sites, so the local people usually take fodder, grass and litter from their private lands while in Makawanpur district people use their community forest for these goods.

The average carbon stock across all four research sites was 206.7 t ha^{-1} which is equivalent to 759 t CO_2 ha^{-1}. The total carbon stock in the four research sites was 478170 t CO_2 equivalents.

Annual Changes in Forest Biomass

Above and Below Ground Tree Biomass

The average changes over one year in above ground tree biomass (AGTB) in the research sites was 3.6 t ha^{-1}. The highest average change was in Gorkha (4.58 t ha^{-1}) followed by Chitwan (3.62 t ha^{-1}), Dolakha (3.4 t ha^{-1}) and Kulekhani (2.72 t ha^{-1}) (Table 6). The community forest in Gorkha was 5 years older than others and grazing is banned, which may account for the higher rates of growth. As mentioned earlier, the average change in below ground tree biomass (BGTB) was calculated by using a fraction 0.2 of AGTB. So, the average change in below ground tree biomass (BGTB) was also highest (0.92 t ha^{-1}) for Gorkha, and lowest (0.54 t ha^{-1}) in Makwanpur (Table 6). The biomass value in the plots in Dolakha exhibited the greatest spread (variance) (Fig 3).

Table 6: Annual Change in Above Ground Tree Biomass (AGTB) and Below Ground Tree Biomass (BGTB)

District	Year	Tree density (ha^{-1})	AGTB (Ct ha^{-1})	Change (Ct ha^{-1})	
				AGTB	BGTB
Makwanpur	1st	900	102.2	+2.7	+0.54
	2nd	888	104.9		
Gorkha	1st	700	199.7	+4.6	+0.92
	2nd	675	204.2		
Chitwan	1st	1457	163.0	+3.6	+0.72
	2nd	1386	166.6		
Dolakha	1st	400	158.5	+3.4	+0.68
	2nd	400	161.9		

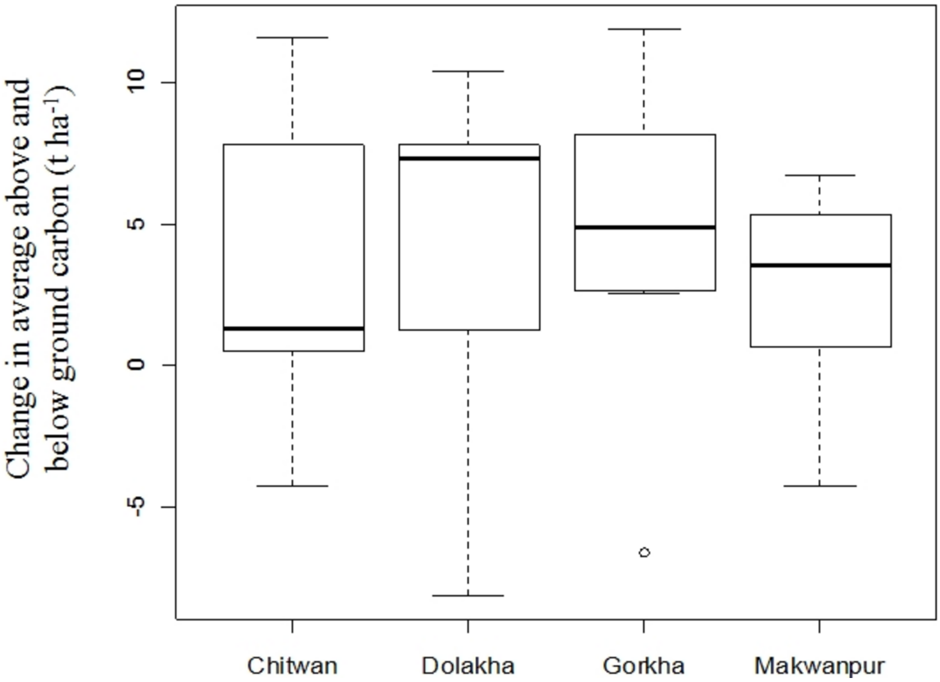


Figure 3: Box and Whisker Plot for Increased above and below-ground Carbon in the Research Sites (t/ha/year)

Litter, Grass and Herbs Biomass (LGHB)

The greatest increase in litter biomass (0.15 t ha^{-1}) and grass and herb biomass (0.04 t ha^{-1}) was found in Dolakha (Table 7). The lowest increases in LB and GHB were recorded in Makwanpur (0.04 t ha^{-1}) and Chitwan (0.01 t ha^{-1}) respectively.

Table 7: Annual Changes in Litter, Grass and Herb Biomass (LGHB) in Four Locations

District	Year	LB (t ha $^{-1}$)		GHB (t ha $^{-1}$)	
		Stock	**Change**	**Stock**	**Change**
Makwanpur	1st	2.25		0.33	
	2nd	2.29	0.04	0.35	0.02
Gorkha	1st	5.32		0.51	
	2nd	5.44	0.12	0.53	0.02
Chitwan	1st	4.78		0.44	
	2nd	4.91	0.13	0.45	0.01
Dolakha	1st	4.37		0.64	
	2nd	4.52	0.15	0.68	0.04

The greatest spread in the leaf litter biomass values in the permanent plots was found in Gorkha whereas the least spread was in Chitwan (Fig 4). For grass and herb, the greatest spread was recorded in Dolakha whereas the least spread was found in Gorkha (Fig 5).

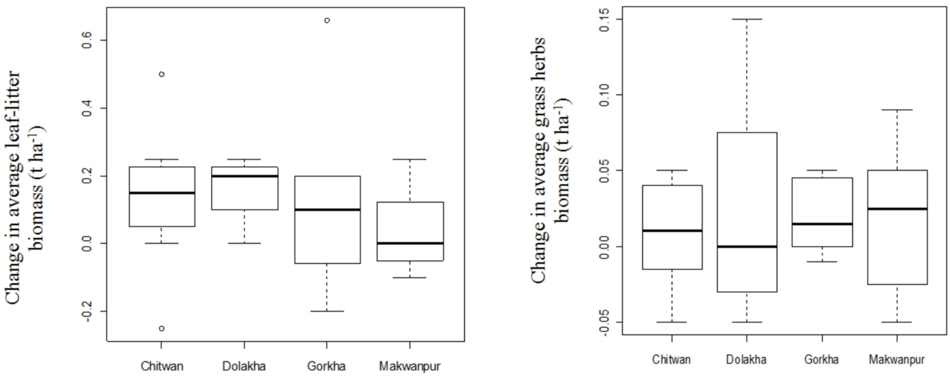


Fig 4: Box and Whisker Plot of Annual Biomass Increment (Left Fig-leaf Litter Biomass, and Right Fig-grass and Herb Biomass)

Annual Change in Total Biomass and Carbon in 4 CFs

The total biomass (all pools) was compared between 2009 and 2010 to estimate the annual change (Table 8). The average annual increment in biomass was 4.36 t ha^{-1}. The highest increment was in Gorkha (5.29 t ha^{-1}), followed by Dolakha (4.65 t ha^{-1}), Chitwan (4.03 t ha^{-1}) and Makwanpur (3.1 t ha^{-1}). The annual increment in biomass was converted to carbon and carbon-dioxide equivalent.

Table 8: Summary of Annual Changes in Biomass Carbon in Four Locations

District and community forest (CF)	Year	Total forest biomass (t ha $^{-1}$)	Change (t ha $^{-1}$)		
			biomass	Carbon	CO_2 equivalent
Makwanpur (Borrow Pit CF)	1st	117.52			
	2nd	120.62	3.10	1.46	5.36
Gorkha (Ludi Damgade CF)	1st	230.45			
	2nd	235.74	5.29	2.49	9.14
Chitwan (Pragati CF)	1st	190.32			
	2nd	194.71	4.39	2.06	7.56
Dolakha (Thansa Deurali CF)	1st	166.51			
	2nd	171.16	4.65	2.19	8.04
Average	1st	176.20			
	2nd	180.56	4.36	2.05	7.52

The reasons why carbon increment was the greatest in Gorkha forest were related to the local forest characteristics as well as to management practices. Users in Gorkha were more aware than in other CFUGs of forest protection and sustainable management of forests, and users in Gorkha follow most of the rules and regulations specified in the forest operational plan. In other forests there were also problems due to illegal activities. Moreover, Gorkha forest was planted 25 years ago (and is therefore at least 5 years older than the others) and rates of biomass increase are therefore greater. Forest fires are a big problem in Chitwan, due to the hot climate and anthropogenic factors. Illegal fires are set to encourage grass growth for fodder, but these sometimes get out of control, with resulting loss of biomass.

The greatest variance in annual change in biomass values was found in Dolakha (Fig 6). The major causes for this are high local variation in slope, aspect and soil types. Variation was also observed in the permanent plots due to management practices and tending operation in different blocks in different years. The forest in Gorkha in comparison was quite uniform.

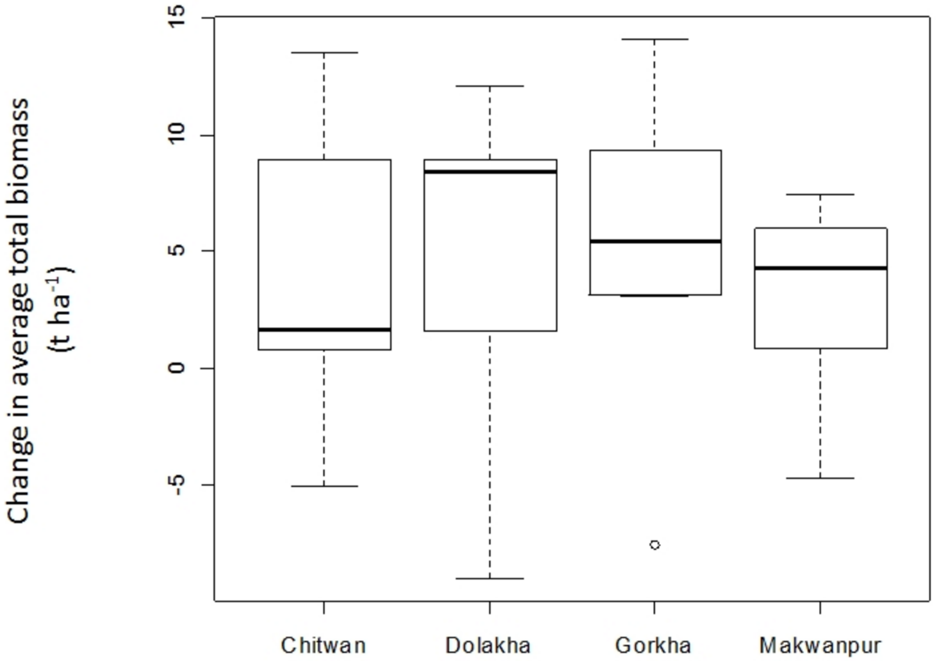


Fig 6: Box and Whisker Plot for the Annual Changes in Total Biomass

Comparison of Results with Other Studies

The forest inventory for this study was conducted in October 2009. Six months later, a carbon inventory was carried out by ICIMOD, ANSAB and FECOFUN in three watersheds in the same study sites (those included in this study, with the exception of Kulekhani). They estimated the mean annual incremental carbon in the three watersheds as 2.67 t ha^{-1} which is slightly higher than reported by this study (2.05 t ha^{-1}), although the difference is probably not substantial (Personal communication). Karky (2008) conducted a forest carbon inventory in three community forests in the similar climatic regions of Nepal. He estimated the annual incremental carbon at 1.13 t ha^{-1} to 3.1 t ha^{-1}. Rana (2008) carried out a forest carbon inventory in a community forest of mid-hills of Nepal where he estimated 1.4 t C ha^{-1} of mean annual incremental carbon. Banskota *et al*. (2008) found 3.7 ton per ha annual forest carbon increment in community forests in Uttarakhand, India. The carbon stock values of this study also compare well to the results of a study by the Asia Pacific Network in 10 community forests in mid hills, which estimated 163.9 t ha^{-1} (Gautam *et al*., 2009). Hence the results of the current study are within the range of estimates already made, and strengthen our understanding that community forest management results in regular increases in forest stock levels, ranging from 1 to 3 tons per hectare per annum, depending on local circumstances.

Conclusions

Community-based forest management in Nepal effectively enhances biomass carbon, and CFM may be a good contributor to REDD+ programmes in the future. Soil carbon increment was not measured in this study as soil carbon does not change measurably over the course of one year. Nevertheless, soil carbon forms a large portion of the overall carbon content of many forest ecosystems, and if the forest is cleared, it may be lost, at least in part. The amount of biomass sequestered in forests under CFM depends on the forest management practices and users awareness level.

Whether the financial value of the annual increments of carbon (around 2.05 tonnes ha^{-1} yr^{-1} according to this study) will be sufficient to encourage more communities to engage in sustainable forest management practices, is another question. This will depend on the price for which carbon credits can be sold, but also on the array of costs at the community level that are associated with REDD+activities, which include opportunity costs, establishment costs, implementation costs, measurement and monitoring costs, and transaction costs. Detailed studies are required in order to estimate these and to come to a cost-benefit assessment.

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