Trained local communities can measure effectively and efficiently the changing carbon stock in their forests using standard forest inventory methods.

Community forest meeting in progress in one of Nepal's community-managed forests *(Bhaskar Singh Karky)*

Carbon Measurement Methodology and Results

4

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Introduction

This Chapter describes the methodology used for estimating carbon in forest land use according to the standards set by the IPCC (2003) for the LULUCF sector. The steps described in the estimation process are derived from the protocol developed by MacDicken (1997), which uses standard forest inventory principles and techniques. Hence, the carbon estimation methodology for India and Nepal is based on standard forest inventory principles and techniques, with minor differences to suit differing field conditions, forest types, local forest management, and available technical resources.

The methodology described is a simple step-wise procedure for carbon estimation in a given piece of community forest with local participation, as is being done by the project Kyoto: Think Global, Act Local in the India and Nepal Himalayan region. The methodology pertains to data collection and analysis of carbon accumulating in the biomass and soil carbon of forests using modern verifiable methods.

Research Sites in India and Nepal

In Uttarakhand, India, much of the altitudinal range between 1600-2200 masl consists of two major forest types: temperate oak, and subtropical pine. These forests are dominated by evergreen species of *Pinus roxburghii* (Chir pine) and *Quercus leucotricophora* (Banj oak). The dominants have a leaf life span of about one year, with older leaves falling as the new leaves expand, or a few weeks later (Singh and Singh 1992). Annual rainfall across the region varies from 1050-2690 mm (Dhar 1987).

There are three research sites in Nepal, located in different geographic regions. Ilam in the Churia range (low hills), at an altitude of 400-800 masl, has a subtropical broad-leaved forest dominated by bamboo, *Lannea grandis*, and *Schima wallichii*. Forests in Lamatar lie in the midhills at an elevation between 1830-1930 masl and are dominated by lower temperate broad-leaved species, particularly of *Schima-Castanopsis*. In Manang, the forest lies in the high mountain range at an elevation range of 3500-4200 masl, representing a temperate conifer forest dominated by *Pinus wallichiana*. This is the upper limit of forest vegetation, a transition between a temperate forest and an alpine grassland. A brief description of the forest sites in India and Nepal is presented in Table 4.1.

Table 4.1: Description of the research sites in India and Nepal

	Van Panchayat Forest Sites in Uttarakhand, India			Community-managed Forest Sites in Nepal		
Research sites	Dhaili	Toli	Guna	Ilam	Lamatar	Manang
Area (ha)	58	103.5	50	47	96	240
Year established	1999	1955	1937	1998	1994	Mid '90s
Total members	1350	1246	204	1800	390	650
Rainfall (cu m)	162-180	162-180	160-180	200	160	40
Temperature	6 - 28^{0}C	6 - 29^{0}C	6 - 29^{0}C	6 - 30^{0}C	3 - 30^{0}C	-5 - 20^{0}C
Altitude (m)	1810 - 1960	1900-2100	1800-1920	400-800	1830-1930	3500 - 4200
Vegetation/ forest type	Himalayan temperate oak forest	Subtropical pine forest/ Himalayan temperate oak forest	Sub tropical pine forest/ Himalayan temperate oak forest	Subtropical broad-leaved	Lower temperate broad-leaved	Temperate conifer
Dominant species	Banj oak *(Quercus leucotrichophora)* mixed with under canopy species Burans *(Rhododendron arboreum)* and Kafal *(Myrica nagi)*	Banj oak *(Quercus leucotrichophora)* and Chir pine *(Pinus roxburghii)*	Banj oak *(Quercus leucotrichophora)* and Chir pine *(Pinus roxburghii)*	Various species of bamboo, *Lannea grandis*, and *Schima wallichii*	*Castanopsis tribuloides* and *Schima wallichii*	*Pinus wallichiana*
Size of permanent plots (m^2)	100	100	100	100	100	250
Number of permanent plots	7 - 15	9 - 15	8 - 10	14	8	9

Carbon Estimation Methodology

Selection of Sites

The criteria for the selection of Van Panchayat community forests user group-managed forest sites from among several surveyed community forests was based on the willingness of community members to participate in training exercises for carbon estimation. Selected sites represent the typical range of areas of VPs/CFUGs, average household size, year of formation, forest condition and type. At least one village-level workshop was held and the participating communities informed about the possible repercussions of climate change and some basic information about global warming. The workshop was participatory, taking inputs from the community in regard to the condition of their forest and forest types, and their views regarding the manner in which training should be conducted. Various rounds of consultations with the village communities in general, and the office bearers of the VPs and CFUGs in particular, were the basis for activities undertaken in community forest areas. The entire field exercise comprising the collection of data necessary for carbon estimation was done in collaboration with local people who were given training on forest survey techniques.

Identifying and stratifying the forest area

The following factors were considered in identifying the different forest strata (hereby referred to as forest type):

- *Dominant tree species.* Sites under a dominant species were regarded as one stratum or type.
- *Stocking density of trees.* Within a dominant type, sites were separated in case they differed substantially in stocking density.
- *Age of tree.* Sites of clearly different age classes were further stratified as carbon sequestration differs markedly with the age of the stand.
- *Aspect and position of hill slopes.* Within a dominant type, sites differing in aspect and position on a hill slope were further stratified because the rate of carbon sequestration varies in relation to these factors. For example, a stand on the south aspect would have far greater productivity than one on the north aspect.

Stratifying the forest ensures that measurements are more alike within each stratum compared to the sample frame as a whole. For the sake of convenience, several maps following detailed discussions were prepared by the community showing the presence of dominant species in different areas and aspects, which were cross-checked during actual field visits (Figure 4.1). In the fieldwork in Nepal, community-managed forests were not stratified because the area of forest was relatively small, with uniform forest cover within each community forest.

Boundary mapping

The identified forest types were mapped jointly by scientists and community members using a mobile GIS system (HP IPaq with NAVMAN GPS and Arc pad), which was logged/traced onto base maps. For this, the entire boundary of the forest type was visited and coordinates marked at all canopy openings. Ordinary Garmin GPS handsets were also used for mapping, where IPaq could not be used.

Pilot survey for variance estimation and sample plot size

A carbon inventory is more intricate than a traditional forest survey as each carbon pool could have a different variance (MacDicken 1997), hence a pilot inventory was carried out to estimate the variance of the main carbon pool, the trees.

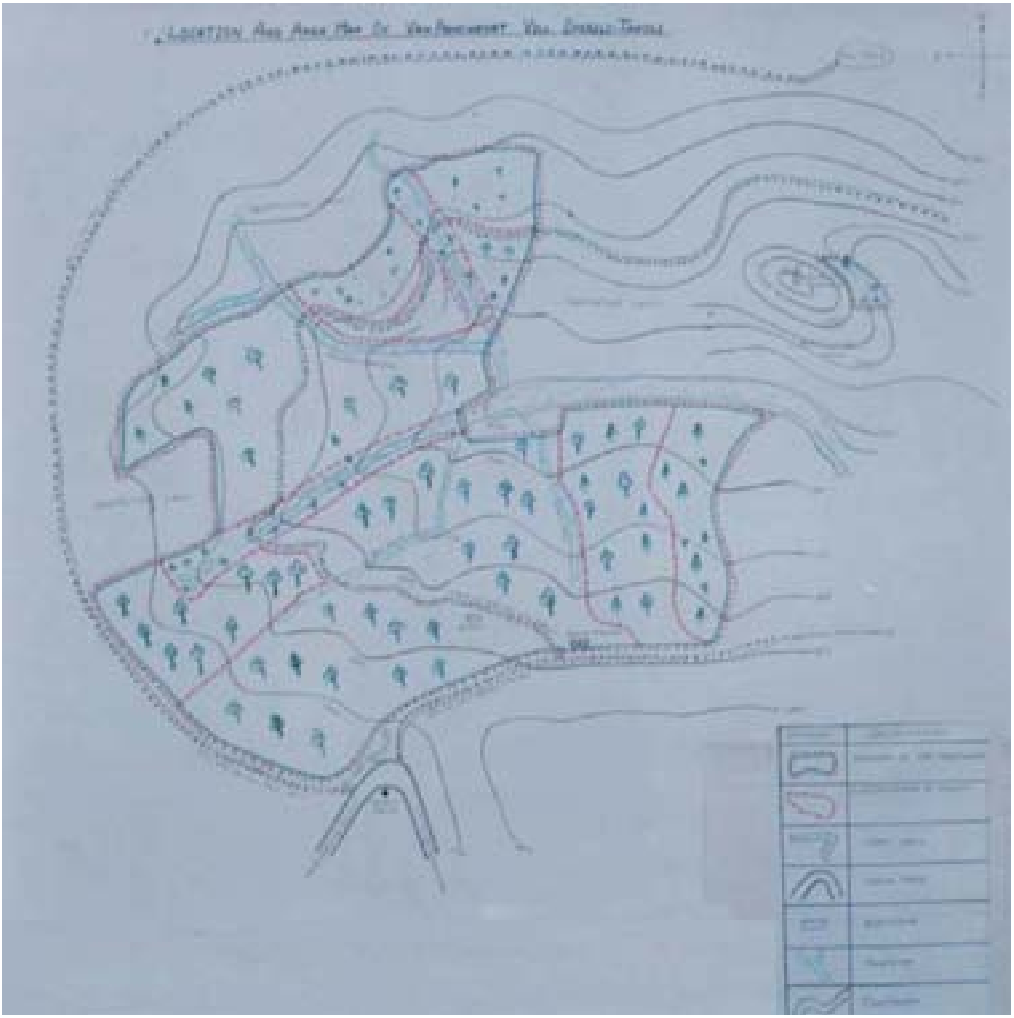

Figure 4.1: Location and forest map of Dhaili VP prepared by the community

In India, a pilot inventory was carried out by laying at least 15 random circular plots for each forest type stratum of 5.64m radius, as recommended by Saxena and Singh (1982), and measuring the circumference at breast height (1.3m). Circumference at breast height (cbh) of all saplings and trees above 4 cm was measured and recorded, while for Nepal, a diameter at breast height (dbh) tape was used to take the dbh recording for trees less than 5 cm.

In Nepal, the area of the circular permanent plots varied in different sites, as the area per tree determined the radii of the plots as described by MacDicken (1997) and as illustrated in Table 4.2.

Table 4.2: Plot radii for carbon inventory plots			
Plot size (sq m)	**Plot radius** (m)	**Typical area per tree** (sq m)	**This size of plot is usual for:**
100	5.64	0 - 15	Very dense vegetation, stands with large numbers of small diameter stems, uniform distribution of larger stems
250	8.92	15 - 40	Moderately dense woody vegetation
500	12.62	40 - 70	Moderately sparse woody vegetation
666.7	14.56	70 - 100	Sparse woody vegetation
1000	17.84	> 100	Very sparse vegetation

Source: MacDicken (1997)

Calculating Optimal Sampling Intensity

The following statistical formula was used to calculate the number of permanent sample plots (n) required for the inventory. Sampling intensity for different sites was shown on Table 4.1.

$$n = \frac{CV^2 t^2}{E^2}$$

where

CV = Coefficient of variation of basal area

t = Value of t obtained from the student's t-distribution Table at n-1 degree of freedom of the pilot study at 10% probability

E = Sampling error at 10%

Permanent plot layout

Locating sample plots. A 'sample design' extension for Arc pad was used to systematically locate the sample plots in the map. The plots were then marked in the field using a mobile GPS system.

Slope correction. While placing permanent plots, care was taken to do a correction for slope in areas where the slope was above 10°. (The slope was calculated using a clinometer). The correction factor used was: LS= L/cos S, where LS is the corrected plot radius, S is the slope angle in degrees, cos S the cosine decimal, and L is the plot radius.

In the CFUGs of Nepal, instead of using the mathematical process for slope correction, the stepping method of surveying on gradient ground was used, which avoids the need for slope calculation. Holding the measuring tape horizontally as illustrated in Figure 4.2 corrects the slope.

Permanent plot measurements

About seven to 15 permanent plots (depending on the calculated sampling intensity/ forest types) of 5.64m radius, as recommended by Saxena and Singh (1982) for the Himalayan forests, systematically laid out with a random starting point marked as 'S' for each forest type (Figure 4.3). Transects perpendicular to the longest side of the forest

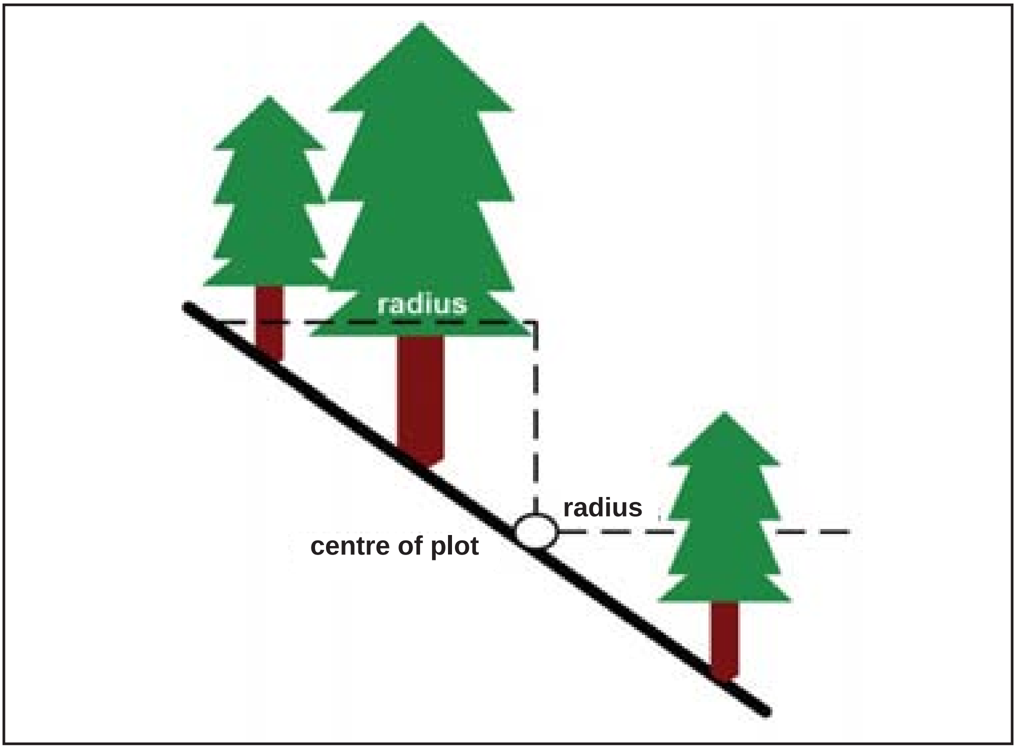

Figure 4.2: The stepping technique of surveying slope correction on a gradient ground

type were placed for a reasonable spread of the plots over the whole area. The transects were parallel to each other and the length of the transects and their bearing were recorded. Using GPS, plots were marked at a similar distance from each other and a map of their location was prepared. For the convenience of the community investigators, the centre of the plot was taken as a tree (marked with white paint) and the radius of the circular plot taken from the centre of this tree. The marking in the centre of the plots proved valuable in annual monitoring as GPS alone could give a few metres of variance in locating the centre of the permanent plot.

For Nepal, the size of permanent plots varied in different sites as the radii of the plots were dependent on distribution of trees, as described by MacDicken (1997), and as illustrated in Table 4.2.

Data recording

Individual trees greater than 16 cm in circumference were measured over the whole plot of 5.64m radius at 1.3 height from the ground for circumference, using a metre tape. Trees which were on the border were considered 'in' if > 50% if the basal area fell within the circle.

Individual trees between 4 and 16 circumference were considered saplings and their circumference determined at collar height in 1m radius plots located approximately in the centre of the large plot. Individuals greater than 1.3m in height and having less than

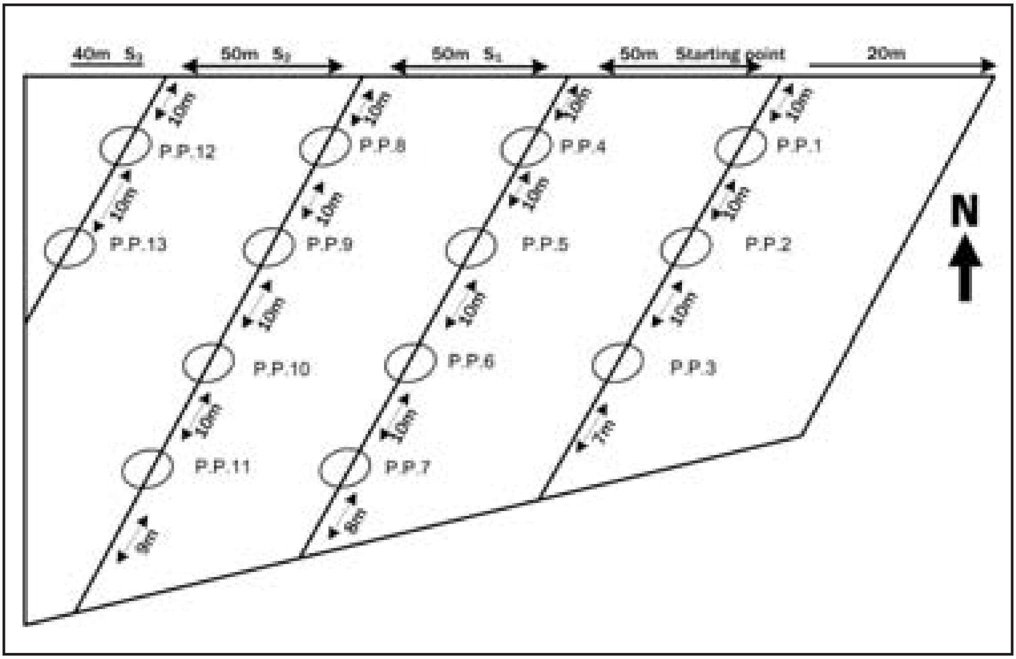

Figure 4.3: Location map of permanent plots of pure oak forest in Dhaili VP

4 cm circumference at collar height were considered seedlings, which were counted in 4 subplots of $1m^2$ placed within the larger (5.64m radius) plot, as depicted in Figure 4.4. For Nepal, trees measuring >5 cm dbh were measured and recorded in the plot using dbh tape. The plot radius for Ilam and Lamatar was 5.64m, whereas for Manang it was 8.92m.

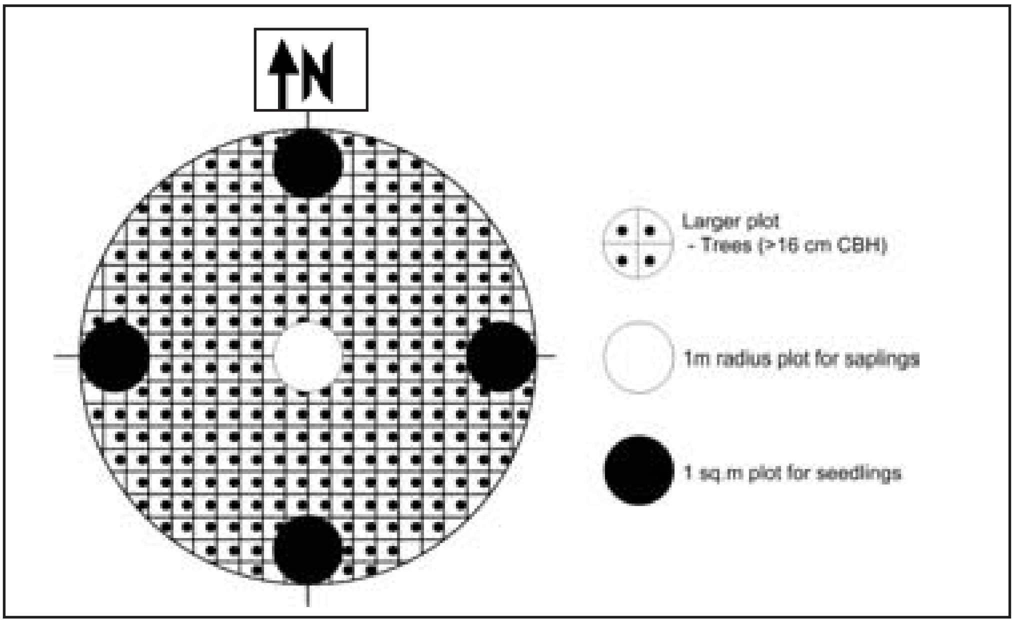

Figure 4.4: Location of plots for sapling and seedling measurements within a larger plot

Data on each measurement was recorded in data collection form and later entered into an Excel spreadsheet. The data was recorded along with species name by two persons, and measurements were redone in cases of discrepancy.

Biomass Estimation

Biomass estimation of trees and saplings

To estimate biomass of trees and saplings occurring in permanent plots, they were categorised into girth classes on the basis of their circumferences taken in October of Year One. The measurements were redone in the same month of Year Two. Using the allometric relations developed by Rawat and Singh (1988) for the Indian Himalayan species the biomass was estimated. In Nepal, the national allometry tables developed by the Department of Forest Research and Survey were used, which had simplified equations that required only dbh as single input variable to calculate volume. The net change in biomass ($\Delta Yr = Yr_2 - Yr_1$) between Yr_2 and Yr_1 was taken as annual biomass accumulation. Half of this change in biomass was taken as the carbon sequestration rate (MacDicken 1997), expressed in t/ha. To convert carbon to carbon dioxide, carbon is multiplied by 44/12 – the ratio of the molecular weight of carbon dioxide to carbon.

Biomass estimation of other plant forms and litter

Four subplots of $1m^2$ in each $100m^2$ plot (5.64 radius) were placed randomly and all above and below ground parts were harvested, placed in previously marked bags, weighed and brought to the laboratory, and oven-dried at 600°C up to constant weight. The biomass of herbs and shrubs were determined at their peak during the September-October months. Biomass was expressed separately for aboveground and below ground components in t/ ha.

The forest floor material was collected from 10, 0.5 x 0.5m quadrants placed randomly in each stratum. All herbaceous live and dead shoots at ground level were harvested. The material on the forest floor was then collected carefully, avoiding contamination with soil as much as possible, and categorised into (i) fresh leaf litter, (ii) partially decomposed litter, (iii) wood (including seeds) litter, and (iv) miscellaneous litter, consisting of material other than the above. The collections were brought to the laboratory, separated by category, and over dry weight determined (Rawat and Singh 1988) in t/ha.

Below Ground Biomass

Below ground biomass estimation is much more difficult than aboveground estimation. To simplify the process for estimating below ground biomass, MacDicken (1997) recommends the use of the root: shoot ratio value of 0.10 or 0.15, which is based on tropical forests. The IPCC (2003) also recommends the use of such default ratios based on root: shoot ratio for different types of forests. For Nepal, root: shoot ratio value of 0.125 was used. For India, allometric relations developed previously (Rawat and Singh 1988) were used.

Soil Carbon Estimation

Two methods are most commonly used for soil carbon analysis: the dry combustion method, and the wet combustion method. The IPCC (2003) recommends use of the dry combustion method for carbon projects, as this method separates organic and inorganic carbon as the latter is removed by acidification. But because of the lack of laboratory facilities and technical know-how, the dry combustion method was not available in Nepal and hence, soil carbon estimation data was referred from literature (Bajracharya et al. 2004) which summarise over 10 other studies carried out in Nepal estimating soil carbon from the midhills region, which is ideal for these research sites.

In India, the researchers' capacities enabled them to conduct soil carbon estimation based on rapid titration method of Walkey and Black (1958), as described by Misra (1968).

To estimate soil carbon percentage, five to seven pits of up to 150 cm depth were dug in different forest types to best represent forest type in terms of slope, aspect, vegetation, density, and cover. From each pit, soil samples were collected from five mineral soil layers (0-10, 10-30, 30-60, 60-90, and 90-150 cm). Misra's rapid titration method was used to measure soil carbon concentration.

Soil bulk density was calculated for each soil depth for which soil carbon was estimated. Soil samples were collected by means of a special metal core sampling cylinder of known volume without disturbing the natural soil structure. Soil samples were oven-dried at 105°C in the laboratory until they reached a constant weight. The weight of oven dried soil samples was divided by its volume to estimate soil bulk density, expressed in g/cc (Misra 1968).

Capacity of VP/CFUG Team Members in Making Measurements

Trained members of the communities have developed sufficient competency in doing field measurements, recording the readings, and using GPS for marking boundaries of forest stratum and permanent plots. Trained CFUG members in two sites in Nepal can do the entire exercise with confidence without outside assistance. However, experience shows that the data analysis part should be left to the experts.

Leakages

Leakage, in CDM terminology, is defined as an unplanned and indirect emission of GHG resulting from a project activity. Direct leakage occurs, for example, if establishing an afforestation or reforestation project on an agricultural land causes farmers farming on this land to move elsewhere to clear the forest in order to continue agricultural activities. All CDM projects must account for direct and indirect leakage, and credit is given only after deducting this amount.

The best approach to accounting leakage is by getting information from the project sites. To account for leakage, a livelihood approach survey was designed to collect data at the household level. This database would then be used for accounting for leakage and finding ways to address it. In the project sites, a random household survey amongst VP/CFUG members was conducted. Data from this survey were verified through focus group discussion. A forest resources use survey will triangulate data for estimating leakage. Currently, only the household surveys have been conducted in the research sites in both countries.

Results

Vegetational parameter

The tree density across the VPs studied in Uttarakhand in different forest types ranged between 83 individual trees/ha and 1271 individuals/ha. The density of trees in all the forest types was reasonably high, except in a degraded site in Dhaili which had a very low density (148 individuals/ha) because of natural factors (this is a rocky area). The basal area of trees was generally above 16 m^2 ha-1 (Table 4.3).

Table 4.3: Vegetation data by forest stratum in the VP forests of Toli, Dhaili and Guna in Uttarakhand, India

VP and forest type	**Growth stage**	**Tree Density** (individuals/ha)	**Basal area** (m^2 ha^{-1})
Toli			
Young banj oak with chir pine forest	trees sap	1016 42	18.8
Chir pine forest with bushy banj oak	trees sap	499 165	16.8
Young pure pine forest	trees sap	653.7 18	24.3
Dhaili			
Even-aged banj oak forest	trees sap	868.8 150	32.5
Mixed banj oak chir pine degraded	trees sap	148	3.8
Dense mixed banj oak forest	trees sap	1271 168	43.5
Guna			
Pure chir pine forest	trees sap	83 18	20.3
Mixed banj oak	trees sap	1222	18.0

In the CFUGs of Nepal, the tree density in Ilam (536 individuals/ha) and Manang (489 individuals/ha) was on the low side compared to Lamatar (2000 individuals/ha), which was also above those of Uttarakhand. However, it is evident that even this forest is young, as the basal area is below 20 m^2 ha^{-1} (Table 4.4). The temperate conifer forest of Manang has a high basal area on account of older trees.

Table 4.4: Vegetation data from three CFUGs of the Nepal Himalaya		
CFUGs	**Density** (individuals/ha)	**Basal area** (m^2 ha^{-1})
Ilam	536	13.4
Lamatar	2000	19.5
Manang	489	33.85

Biomass in community-managed forests of Uttarakhand, India and Nepal

The tree biomass in the community forests of Uttarakhand was much higher than tree biomass in the community forests of Nepal. The biomass of banj oak *(Quercus leucotrichophora)*-dominated forest types was generally above 308.0 t ha^{-1}, and the biomass of chir pine *(Pinus roxburghii)*-dominated forests was marginally lower (Table 4.5). The contribution of herbs and shrubs in the total vegetation biomass areas of all the forest types was between 1.6 and 6.7 t ha^{-1}.

Table 4.5: Above and below ground biomass variations across Van Panchayat forests in Uttarakhand, India			
VP and Forest stratum	**Above and below ground biomass** (t ha^{-1})		
Dhaili VP forest	**Year 1**	**Year 2**	**Year 3**
Even-aged banj oak forest	344.0 (3.4)	353.0 (3.3)	358.0 (2.7)
Dense mixed banj oak forest	511.0 (5.3)	520.5 (5.7)	528.0 (4.5)
Mixed banj oak with chir pine	38.0 (2.0)	42.0 (1.7)	46.5 (1.6)
Toli VP forest			
Young banj oak with chir pine forest	314.0 (6.7)	322.0 (6.5)	330.0 (6.6)
Chir pine with bushy banj oak	118.0 (3.9)	125.1 (3.8)	130.0 (2.9)
Young pure chir pine forest	139.0 (2.0)	148.0 (2.2)	156.0 (2.0)
Guna VP			
Young pure chir pine forest		20.6 (2.1)	28.2 (2.0)
Mixed banj oak forest		308.0 (5.2)	316.8 (4.9)

The values of herb+shrub biomass are given in parenthesis

In the community forests of Nepal, the tree biomass of Ilam and Lamatar was >100 t ha^{-1}, whereas for Manang, it was approximately half of this value (Table 4.6). These figures are considerably lower than in India, which suggests that the forests in Nepal are either younger (such as in Lamatar), or more sparse (such as in Manang). It must be noted that the figures for Nepal only account for aboveground biomass of trees >5 cm dbh and excludes biomass in herbs/grass and litter, and those <5 cm dbh. Below ground biomass is calculated by taking a default value of 12.5% of the aboveground biomass. The figures in parenthesis show aboveground biomass only.

Table 4.6: Annual variation in tree biomass in three CFUGs in the Nepal Himalaya			
CFUG	**Above and below ground biomass** (t ha^{-1})		
	Year 1	**Year 2**	**Year 3**
Ilam	115.88 (103)	121.5 (108)	128.25 (114)
Lamatar	102.38 (91)	104.63 (93)	108 (96)
Manang	61.88 (55)	NA	66.38 (59)

Note: The values for aboveground biomass of dbh >5cm are given in parenthesis

Carbon and CO_2 sequestration rates

Referring to Tables 4.7 and 4.8, the mean carbon stocks across all community forests studied for both Uttarakhand, India and Nepal varied between 30.94 $tCha^{-1}$ (Manang on the 1st year) and 155.4 $tCha^{-1}$ (Dhaili VP on the 3rd year). The mean for Uttarakhand, India was 117.29 $tCha^{-1}$ while for Nepal it was only half this value. In terms of CO_2, the mean CO_2 between the six sites in India and Nepal varied between 113.47 tCO_2ha^{-1} in Manang on the 1st year, and 569.85 tCO_2ha^{-1} in Dhaili on the 3rd year.

Table 4.7: Annual variation in carbon stock by forest type in the Van Panchayats of Uttarakhand, India and their mean carbon sequestration rates				
	Carbon mass (t ha^{-1})			**Mean c sequestration rate** ($tCha^{-1}yr^{-1}$)
	Year 1	**Year 2**	**Year 3**	
Dhaili VP forest				
Even-aged banj oak forest	172.1	176.5	179	3.4
Dense mixed banj oak forest	255.7	260.2	264	4.15
Mixed banj oak chir pine degraded	18.8	20.8	23.25	2.2
Mean C-stock			155.4	
Toli VP forest				
Young banj oak with chir pine forest	156.9	161.2	165	4.05
Chir pine forest with bushy banj oak	58.9	62.4	65	3.05
Young pure chir pine forest	69.5	74.0	78	4.25
Mean C-stock			110.26	
Guna VP forest				
Young pure chir pine forest	-	10.3	14.1	3.8
Mixed banj oak forest	-	154.0	158.4	4.4
Mean C-stock			86.2	
Mean C-sequestration rate across the VP forest				3.7(13.57$tCO_2ha^{-1}yr^{-1}$)

The community forests of both India and Nepal sequester carbon. The mean sequestration rate of community forests studied in India and Nepal is close to 2.79 $tCha^{-1}yr^{-1}$, which translates to 10.23 $tCO_2ha^{-1}yr^{-1}$. The sequestration rates for the community forests of Uttarakhand, India is close to 3.7 $tCha^{-1}yr^{-1}$ (average of three years) or 13.57 $tCO_2ha^{-1}yr^{-1}$, which is twice the rates of Nepal (1.88 $tCha^{-1}$ yr^{-1} or 6.89 $tCO_2ha^{-1}yr^{-1}$) but lower than the range reported for the Central Himalayan forests by Rana et al. (1989). Rana et al. reported a 4.5 to 8.4 $tha^{-1}yr^{-1}$ of carbon in chir pine

(Pinus roxburghii), mixed broad-leafed forest, and pure chir pine *(Pinus roxburghii)* forests. A study from the inner Terai region in Nepal shows carbon sequestration rates of 2 $tha^{-1}yr^{-1}$ from aboveground biomass (including under story biomass) and soil organic carbon (SOC) of up to 0-20cm depth (Aune, et al. 2005) which is closer to the mean of three sites sequestering 2.79 t C ha^{-1} yr^{1} (10.23 $tCO2ha^{-1}yr^{-1}$).

The carbon data for Nepal in Table 4.8 consists of biomass of aboveground plants with >5 cm dbh, and below ground biomass, but excludes SOC, carbon in herbs/grass and litter, and those <5 cm dbh.

Table 4.8: Annual variation in carbon stock in three community-managed forests of the Nepal Himalaya and their mean carbon sequestration rates

CFUGs	**Carbon mass** (tha^{-1})			**Mean c sequestration rate** ($tCha^{-1}yr^{-1}$)
	Year 1	**Year 2**	**Year 3**	
Ilam	57.94	60.75	64.13	3.1
Lamatar	51.19	52.32	54.00	1.41
Manang	30.94	NA	33.19	1.13
Mean C- sequestration rate across community forests				1.88 (6.89 $tCO_2ha^{-1}yr^{-1}$)

Soil carbon

Carbon in the deeper layer of the soil remains sequestered for years unless the aboveground forest is disturbed. Soil carbon is distributed in a deeper layer of soil, possibly due to (1) decrease in soil carbon turnover, with soil depth resulting in higher soil carbon accumulation per unit of carbon input in deeper layers; (2) additional soil carbon leaches from shallower to deeper layers to soil; and (3) carbon moves down vertically through soil organisms (Jobbagy and Jackson 2003).

Soil carbon concentrations across all forest types studied ranged between 1.6 and 3.7% at the topsoil layer (0-10 cm) (Tables 4.9-4.11). Carbon content in the topsoil layer was maximum in banj oak community forests of Uttarakhand. Species with deep roots hold a great potential for carbon sequestration in deeper soil layers. For example, banj oak forests with massive root systems and deep soil are expected to be far more effective in carbon sequestration than other species having shallow roots. The soil carbon in the forests types studied remained close to 1.0%, even at 150 cm depth. Evidently, we will miss a large amount of soil carbon if sampling is limited to top 30-40 cm soil, as is the general practice worldwide. All forests types in the community forests studied in Uttarakhand had soil carbon of over 200 t ha^{-1} up to 150 cm depth (Tables 4.9-4.11), which in CO_2 terms translates to approximately 733 tCO_2ha^{-1}. The data shows that forest soils in the Himalayan region can have up to two times more soil carbon than the amounts reported by sampling 20-30 cm soils.

Table 4.9: Vertical distribution of soil carbon by forest type in Dhaili Van Panchayat ($tCha^{-1}$)			
Soil depth (cm)	**Even aged banj oak forest** ($tCha^{-1}$)	**Mixed banj oak chir pine degraded** ($tCha^{-1}$)	**Dense mixed banj oak forest** ($tCha^{-1}$)
0-10	24.64 (2.2)	17.12 (1.6)	25.41 (2.1)
10-30	31.36 (1.4)	27.82 (1.3)	29.76 (1.2)
30-60	43.20 (1.2)	30.00 (1.0)	44.64 (1.2)
60-90	46.80 (1.2)	46.20 (1.1)	35.34 (0.95)
90-150	78.00 (1.0)	84.00 (1.0)	62.40 (0.80)
Total soil carbon ($t\ ha^{-1}$)	**224.00**	**205.14**	**197.55**

Note: The percent values for soil carbon are given in parenthesis.

Table 4.10: Vertical distribution of soil carbon by forest type in Toli Van Panchayat ($tCha^{-1}$)			
Soil Depth (cm)	**Young banj oak with chir pine forest** ($tCha^{-1}$)	**Chir pine forest with bushy banj oak** ($tCha^{-1}$)	**Young pure pine forest** ($tCha^{-1}$)
0-10	44.77 (3.7)	27.60 (2.4)	31.28 (3.4)
10-30	41.48 (1.7)	36.48 (1.6)	44.00 (2.2)
30-60	63.75 (1.7)	43.20 (1.2)	66.00 (2.0)
60-90	50.70 (1.3)	43.20 (1.2)	46.80 (1.3)
90-150	78.00 (1.0)	64.80 (0.90)	79.20 (1.1)
Total soil C ($t\ ha^{-1}$)	**278.70**	**215.28**	**267.28**

Note: The percent values for soil carbon are given in parenthesis.

Table 4.11: Vertical distribution of soil carbon by forest type in Guna Van Panchayat ($tCha^{-1}$)		
Soil depth (cm)	**Pure chir pine forest** ($tCha^{-1}$)	**Mixed banj oak forest** ($tCha^{-1}$)
0-10	22.00 (2.2)	25.41 (2.1)
10-30	44.00 (2.0)	31.36 (1.4)
30-60	46.80 (1.3)	50.40 (1.4)
60-90	39.60 (1.1)	35.34 (0.95)
90-150	79.20 (1.1)	62.40 (0.80)
Total soil carbon ($t\ ha^{-1}$)	**231.60**	**204.91**

Note: The percent values for soil carbon are given in parenthesis.

According to previous studies and literature (Bajracharya et al. 2004), the mean SOC pool to a depth of 1m in the middle hills is estimated for the forest to be 89.1 tCha-1 (227 tCO_2ha^{-1}), as shown in Table 4.12. The SOC values in the Nepal Himalaya are less than those of Uttarakhand, where the mean C pool is 154 $tCha^{-1}$ (565 tCO_2ha^{-1}) up to a soil depth of 90 cm. This may be because forest biomass is higher in the research sites of Uttarakhand, India than those of the Nepal research sites, and even for these sites where the soil tests were conducted the forest cover could be less than those for sites in India.

Table 4.12: Mean SOC pool and total stock for different land uses in the midhills of the Nepal Himalaya			
Soil Depth (m)	**SOC** (%)	**BD** (Mg/m)	**Mean C pool** ($tCha^{-1}$)
Forests 0-0.30m	2,31	0,7	48.5
Forests 0.3-1m	0,58	1	40.6

Source: Bajracharya, et al. 2004.

It would be interesting to link these results from biomass with existing CDM prices for CO_2, as stated by Ranganathan (2007), which is between US$ 12 to 15 per tonne of CO_2. The mean CO_2 sequestration rate for India of 13.57 t $CO2ha^{-1}yr^{-1}$ would be worth US$ 162.84 $ha^{-1}yr^{-1}$ at the rate US$ 12 per tonne CO_2, and US$ 67.85 $ha^{-1}yr^{-1}$, even if the prices were as low as US$ 5 per tonne of carbon. For Nepal, the 6.89 t $CO_2ha^{-1}yr^{-1}$ would be worth US$ 82.68 $ha^{-1}yr^{-1}$ at US$ 12 per tonne, and US$ 34.45 $ha^{-1}yr^{-1}$ at US$ 5 per tonne. These figures could be significant for the whole of the Himalayan region where local communities practice community forest management.

The prices for CO_2 represent prices for certified emissions reduction (CERs) issued for energy projects. The market for CERs from Clean Development Mechanism (CDM) forestry projects has not yet been developed. These projects do not receive regular CERs, only temporary credits (tCERs), and the market value of temporary credits is likely to be much lower than for regular CERs. The value of CERs from forest management projects such as these is completely unknown, as CERs are not yet tradable.

Some Constraints in Field Measurement in Estimating Carbon

One of the advantages of using a hand-held computer is that the map appears on the screen and it is much more participatory, as everyone can see the map. However, downloaded base maps from the Internet were not accurate. For instance, it would show the wrong location on the map. These maps, because they are large files, also made the computer crash much more frequently.

The iPaq batteries ran out within 45 minutes and recharging was a problem, especially in places where there was no electricity. Garmin handsets were much more reliable and durable as they had longer battery life and batteries were easily available.

The locals developed the competency to turn on the GPS, find permanent plots, and mark and track points, hence they preferred Garmin GPS handsets over hand-held computers which were more complex, requiring computer skills and ArcPad software skills.

Out-migration in the village is a common problem. Because handling GPS needed technical skills, literate community members were included in the research team. But they were the first ones to migrate from the village, making training new members in the next year a routine job.

Conclusion

From the study results data, the mean sequestration rate of the community forests in India and Nepal is close to 2.79 $tCha^{-1} yr^{-1}$, which is 10.23 $tCO_2ha^{-1}yr^{-1}$. It is clear that these community-managed forests, covering close to 7.5 million ha areas in the Himalayan region, are major carbon sinks. The data presented in the Chapter shows the level of carbon stored in forest biomass and soil. More important is the danger of losing this pool if communities convert their forests into agricultural use or urban expansion; the potential emission increment levels from deforestation would be significant. If these sinks are to be conserved, it is essential that poor and marginalised hill communities that have been conserving their forests on a sustainable basis without outside financial support be provided financial incentives for the global services they have rendered. This will reduce their opportunity cost. The methodology mentioned in this Chapter is an important means of quantifying carbon sequestration levels if communities decide they want to claim payments for their global ecological services. Carbon estimation is also necessary for monitoring the pool levels and in identifying strategies and management interventions to further improve efficiency. Witnessing the rise in human and livestock population in the Himalayan region in the past decade, carbon trade could be an incentive for forest conservation and management if recognition is provided to community forestry under the Kyoto Protocol.