https://doi.org:10.3126/banko.v29i2.28095

Quantification of carbon stock under different land use regimes of Chitwan district, Nepal

A. Poudel[1]*, H. L. Shrestha[2] and R. M. Bajracharya[3]

Carbon sequestration in terrestrial ecosystems is gaining a global attention, including Nepal, to address the issues of climate change. Since, the quantification of carbon stock under different land use systems with focus on both biomass and soil profile is lacking, objective of this paper is to quantify carbon stock in biomass and in soil profile under different land use regimes, namely community forest, leasehold forest and agricultural land of Chitwan district. The carbon stock in biomass was calculated using the standard allometric equations, and Dry Combustion Method was used to determine the Soil Organic Carbon (SOC). The carbon content in above ground tree biomass (AGTB) was found to be higher (81.25 t/ha) in community forest than in leasehold forest (80.09 t/ha). The carbon stock in above ground sapling biomass (AGSB) was calculated only for the community forest, and was found to be 3. 67 t/ha. Similarly, the density of leaf litter, herbs and grasses (LHG) was also found to be higher (9. 25 t/ha) in the community forest in comparison to leasehold forest (6.45 t/ha). Further,the root carbon stock density was also higher (16.25 t/ha) in the community forest than in the leasehold forest (16.02 t/ha). However, the SOC density was highest in the agricultural land (73.42t/ha) followed by the community forest (66.38 t/ha)and the leasehold forest (52. 62 t/ha). Overall, the carbon stock was highest in the community forest (176.8 t/ha) then in leasehold forest (155.18 t/ha) followed by the agricultural land (73.42 t/ha). Hence, this study shows that well managed community forest can contribute significantly in offsetting global carbon emission.

Keywords : Climate change, community forestry, leasehold forestry, REDD+, total carbon stock

Global warming has become the most concerning issue these days both to scientists and environmentalists. Recent estimate indicate that human activities are currently responsible for annual global carbon emission of about 10 Giga ton (Gt) of which 1.5 Gt is a result of land use change (Canadell *et al*., 2007).

10,000 years ago,forest covered 6 billion ha land area of earth, and now it has come down to 4 billion ha, with an average annual net loss of about 5. 2 million ha within in the past ten years (FAO, 2012). Forest can contribute up to 20% of the global emission of carbon dioxide annually,which is more than the one contributed by transportation sector (Acharya *et al*., 2009). Reducing emission from forest-based greenhouse gases (GHGs) is critical in curbing global warming, and so, the United Nations Framework Convention on Climate Change (UNFCC) introduced Reducing Emission from Deforestation and Forest Degradation (REDD+), a carbon offset program in 2005 (COP 11). REDD+ could be cost effective measure to address climate change (Acharya *et al*., 2009). Taking action on carbon sequestration will not only help to lower the concentration of GHGs but will help to improve soil properties, and have positive impact on environment (FAO, 2001). Therefore, quantifying the carbon stored in

1 Graduate Student, Asian Institute of Technology (AIT), Bangkok, Thailand. *Email : poudel. asmita09@gmail. com
2 Associate Professor, Kathmandu Forestry College; Coordinator, UNIGIS Program
3 Visiting Faculty, Department of Environmental Science and Engineering, Kathmandu University

different carbon pools is gaining a global attention. Forest is one of the largest pools, sequestering significant amount of carbon and preventing the carbon stored within it from being released into the atmosphere. A recent study conducted by the United Nations Environment Program (UNEP) reveals that tropical and subtropical forest store largest amount of carbon followed by Boreal forest whereas the tundra biome has the highest density of carbon storage (Trumper *et al.,* 2009).

Soil is another largest terrestrial carbon pool (Chan, 2008). It is estimated that around 1,200 to 1,800 Giga tons of carbon is stored in soils worldwide. Soil pool is 3. 3 times the size of atmospheric pool and 4. 5 times the size of vegetation pool. Hence carbon sequestration has potential to offset 5−15% of global fossil fuel emission (Dahal and Bajracharya, 2010).

The amount of carbon that gets sequestered in biomass and soil is dynamic as it depends on land use change (Shrestha and Singh, 2007), types of species with different management regimes and soil profile. This signifies that there must be a regular accounting of carbon emission, carbon removal and carbon stock which is limited in developing countries like Nepal. As Nepal harbors 118 ecosystems with 36 vegetation types and 35 forest types (MoFS, 2009), regular quantification of carbon stock is a necessity.

According to the World Resources Institute (2008), Nepal ranks 11th in the world for the emission of GHGs, and about 80% of emission is only from forest and grassland conversion (MoPE/UNEP, 2004). Implementation of the United Nations Framework Convention on Climate Change (UNFCCC) introduced REDD+ program, in developing countries like Nepal to reduce such emission, is expected to build capacity in measuring and monitoring forest carbon stock, opportunity for reducing poverty, enhancing livelihood, preserving biodiversity, and promoting adaptation to climate change. In spite of these opportunities, there are significant challenges for effective engagement with REDD+ in Nepal due to lack of- research on quantification of carbon stock with standard scientific method, regular monitoring the change in carbon stock, and setting baseline scenario for assessing emission reduction (Acharya *et al*., 2009).

For studying carbon sequestration, the authors have pointed out that quantification of carbon stock, their changes over time and quantification of associated uncertainties are prerequisite for reporting removal of carbon from atmosphere and making a good mitigation strategy for climate change effects.

In the context of Nepal, quantified data on carbon stock using standard scientific procedure under different land use system at ecosystem-level is lacking. With the emergence of REDD+, much focus has been diverted towards community forest neglecting other locally managed forest regimes which occupy three quarter of the total forest area. Failure to include these forest in national REDD+ program could heighten social and political tension. Therefore,this study was carried out with an objective to quantify and compare the carbon stocks in forest biomass and in soil profile under different land use regimes, *viz*. community forest, leasehold forest and agricultural land of Kayerkhola watershed, Chitwan district, Nepal. Such studies are necessary to assess the effects of forest management, cropping system option on carbon dynamics and to guide management decisions that deal with enhancing carbon sequestration potential of an ecosystem as highlighted by Wutzler *et al*. (2011).

As carbon sequestration is a win-win strategy to reduce GHG emission, there has been increasing pressure for accounting the carbon stocks in vegetation and soil ascertaining the potential of these reservoirs as carbon sink. However, there is high probability for these reservoirs to become carbon source in absence of their proper management. On the other hand, in the absence of baseline data, Nepal will face significant challenges for effective engagement with REDD+. Hence, this study will be helpful for the establishment of baseline data to enable us to-project carbon sequestration over time, make the public aware of the potential of terrestrial system to sequester carbon in mitigating climate change issues; adopt different strategies and policies to enhance the potential of different forest regimes as carbon sinks and minimize carbon emission; to prove our contribution towards emission reduction in the world; and to obtain financial incentives.

Materials and methods

Study area

The study was conducted at the Kayerkhola Watershed, Ward No. 5 of Shaktikhore Village Development Committee, Chitwan district, Nepal (Figure 1). The study was carried out in December 2012. The Kayerkhola Watershed represents the tropical and subtropical region. It is located between 27^{o} 40’07. 79” N and 84^{o} 33’25. 88” E. The altitude of this watershed ranges from 245 m to 1,944 m above mean sea level. It covers an area of 8,002 ha of which 2,381. 96 ha area is occupied by community forest (CF) which is locally managed by 15 community forest user groups (CFUGs). Beside community forest, leasehold forest and agricultural land are other major land use regimes within this watershed. Sub tropical hill Sal (*Shorea robusta*) mixed with other deciduous trees are major forest types found in this watershed. This Watershed is inhabited by the forest-dependent indigenous community of Chepang and Tamang (ANSAB/ICIMOD/NORAD, 2010).

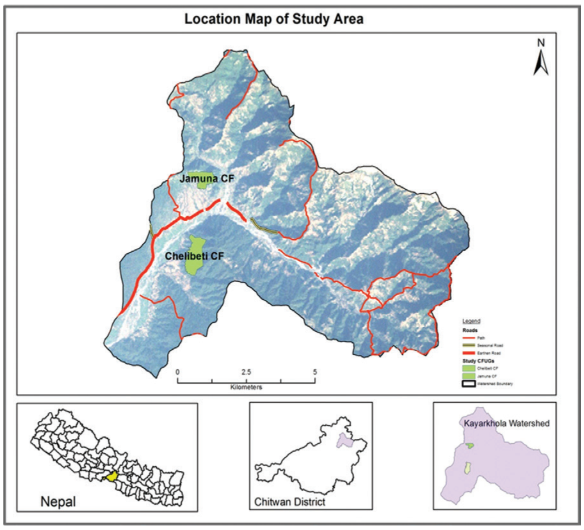

Figure 1 : Map showing the location of the study area

The Kayerkhola Watershed was chosen as it is one of the sites where the REDD+ Project (world's first carbon offset project),at pilot phase, is being implemented by the International Centre for Integrated Mountain Development (ICIMOD), Asia Network for Sustainable Agriculture and Bioresources (ANSAB) and the Federation of Community Forest Users, Nepal (FECOFUN) with the financial support of the Norwegian Agency for Development Cooperation (NORAD).

For the purpose of the study, the sampling was carried out in the Jamuna Community Forest and Leasehold Forest, the Chelibeti Community and Leasehold Forest and agricultural land.

Method used

The study was conducted adopting the methodology of Subedi *et al*. (2010).

Forest sampling

In order to quantify the carbon stock in the forests and the agricultural land, a total of 8 sample plots were considered- 2 plots within the community forest, 2 plots within the leasehold forest, and 4 plots for collecting the soil samples from the agricultural land. Concentric circular sample plots with different radii were selected randomly, and laid out within the sampling area for the measurement of above ground biomass of trees, saplings, seedlings, leaf litter, herbs and grasses. The outermost plot with 8.92 m radius was laid out to measure the above ground tree biomass (AGTB). The next sub-plot with 5.64 m radius was established for the measurement of above ground sapling biomass (AGSB). Likewise, the next sub-plot with 1 m radius was established for counting regeneration, and the innermost sub-plot with 0.56 m radius was established for taking the samples of leaf litter, herbs and grasses (LHGs) and for the calculation of soil organic carbon (SOC). The latitudes, longitudes, slope and aspects of each sample plot were recorded with the help of Global Positioning System (GPS) set.

Soil sampling

Individual soil samples from 0−15 cm and 15−30 cm depth were collected with the help of standardized metallicsoil sampling corer (volume : 104. 09 cm^{3}),and weighed in the field to record their fresh weight. Similarly, the composite soil sample (mixture of soil from both the layers) of around 100 g was collected from each sample plot so as to determine the concentration of SOC.

Data analysis

For the calculation of the AGTB and carbon stock,allometric equation developed by Chave *et al*., (2005) was used. The AGTB of a sample plot was converted to carbon stock density by using the default fraction of 0. 47 (IPCC, 2006). The saplings with diameter ≥ 1cm but< 5cm at 1. 3 m above ground level was measured while those with diameter <1 cm at breast height were counted as regeneration. Samples of leaf litter, herbs and grasses from 1 m^2 plot were collected in plastic bags, and weighed to determine their fresh weight. The collected soil samples were brought to the laboratory of the Kathmandu University to measure their oven dry weight to determine the moisture content and finally to estimate the SOC. MacDicken's root to shoot ratio of 1 : 5 (MacDicken, 1997) was used to calculate the carbon content in the root biomass. Adding carbon content from all the carbon pools yielded the total biomass from the forest. The SOC was calculated using the equation of Pearson *et al.* (2007). For determination of the SOC, bulk density was calculated by dividing the oven dried weight (at 105°C after 24 hours) with the total core volume (Blake and Hartage, 1986). Similarly, the SOC% was determined by adopting the Dry Combustion Method (Nelson and Sommers, 1982).

Results and discussion

Plant species diversity

During the fieldwork, 18 different tree species were recorded in eight sampling plots. *Shorea robusta* (Sal), *Lagerstroemia parviflora* (Botdhayero), *Mallotos phillipinensis* (Sindure) and *Cassia fistula* (Rajbriksha) were the major species occurring in the community forests (Figure 2).

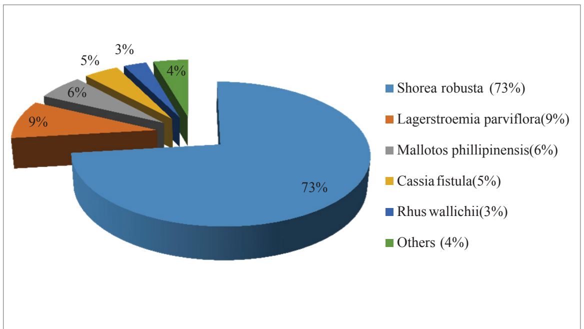

Figure 2 : Plant species density in community forest

S. robusta and *Rhus wallichii* were found to be dominant in the leasehold forests. Besides, different fodder species such as *Ficus semicordata*, *Albizia juriblissin*, *Quercus floribunda, Dendrocalamus strictus,* etc., and the fruit trees like mango and pineapple were also observed; the fruit trees were reported to be grown to meet the need of the forest-dependent communities (Figure 3).

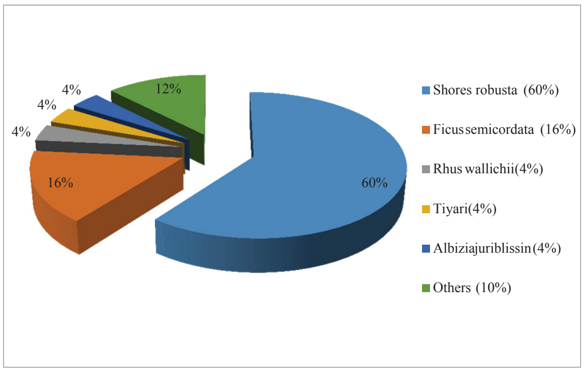

Figure 3: Plant species density of leasehold forest

Forest carbon stock

The carbon content in the AGTB in the community forest (CF) and leasehold forest (LF) were (81. 25 t/ha) and (80. 095 t/ha) respectively (Table 1). The carbon density in the AGTB was found to be higher in the CF than in the LFas the tree density, diameter and height which influence the AGTB value were comparatively higher in the CF. Similarly due to the higher density of trees with large canopy cover and restriction in the collection of leaf litter, twigs, fallen branches and fodder, biomass and carbon content in the LHGs in the CF was found to be higher. The demand for leaf litter, fallen branches, twigs and fodder is fulfilled from the LF when it is opened for its members. Although the difference between the carbon stock in the CF and the LF was minimal, the standard deviation in the AGTB of the LF was higher. The LF consisted of more number of young trees (pole-size) than mature ones. When these young trees reach maturity, the LF holds the potential to store significant amount of carbon. The average carbon stock (80. 47 t /ha) in the AGTB as detected in this study is comparable with the ones reported by Baral *et al*. (2009) and by Oli and Shrestha (2009) for the Terai forest, 80. 47 t/ha and 76 t/ha, respectively. However, Shrestha and Singh (2007) has reported the AGTB for

Sal forest to be 169 ± 26 t/ha. The calculation of the carbon content in the leaf litter, grasses, and herbs including twigs in both the CF and LF indicated that these carbon pools contributed significantly in the sequestration of atmospheric carbon. The root biomass was calculated as 20% of the AGTB. The root biomass and the carbon content were also found to be higher in the CF than in the LF.

The AGSB was recorded from only one sample plot from the Jamuna CF as there were significant number of young trees which contribute in increasing the carbon stock of that CF. The carbon content in the AGSB was found to be 3. 67 t/ha.

Table 1: Biomass and Carbon Content (tons C/ha) in different Carbon Pools of Forest

S.N.	Carbon Pools	Community Forest	Leasehold Forest
1	AGTB	172.89	170.41
2	C (AGTB)	81.25	80.09
3	AGSB	7.8	
4	C(AGSB)	3.67	
5	LHG	19.65	13.70
6	C (LHG)	9.25	6.45
7	BB	34.58	34.08
8	C (BB)	16.25	16.02

Soil Organic Carbon

The result showed that the SOC (t/ha) up to 30 cm depth was highest in the agricultural land (73. 42 t/ha) as compared to the CF (66. 38 t/ha) and the LF (52. 62 t/ha). This might be due to the application of farm yard manure (FYM), compost and crop rotation which are some of the activities included in soil management practice (SMP), and these lead to increase SOC accumulation by three fold in soils (Dahal and Bajracharya, 2010). In addition, the soils in agricultural land have greater clay content (26. 75%) than in the community and leasehold forests (26. 75%) which might have contributed to high SOC-level in agricultural soils (Lal, 2005); clay consists of bonding cations like Ca, Al or Fe leading to accumulation of organic carbon in comparison to other soil types. The nitrogen concentration in soils was also found to be highest in the agricultural soils which might have also contributed in maintaining higher SOC-level than in the community and leasehold forests (Liddicoat *et al.,* 2010; Lal, 2005). Further, slower turnover of roots, slower decomposition of leaf litter due to low soil quality, cooler and drier condition under forest, inhibition of soil fauna, low or no understory vegetation, enhanced rate of loss of carbon as aggregation is reduced, presence of rocky and shallow soil might be some of the reasons for lower SOC-level in forest soils (Chan *et al*., 2008). The SOC-level was found to be higher (66. 38 t/ha) in the CF than in the LF (52. 62 t/ha). This may be because of less sand content in the CF soil than in the LF soil. Similar result was reported in the study conducted by Shrestha and Singh (2007). The SOC-level was high in the cultivated land (bari) followed by degraded forest, paddy field (khet), *Schim-Catanopsis* forest, managed dense *S. robusta* forest and Pine mixed forest. The SOC% was found to be in decreasing order in all the studied land use regimes, indicating reduced organic matter and decomposition at increasing depth (Table 2).

Table 2 : SOC in different land use regimes

S. N.	Land Use	SOC	Min	Max	Mean	Median	St. dev
1	C F	CARBON	46.54	80.15	66.38	68.455	12
2	L F	CARBON	27.57	85.36	52.62	48.78	25.67
3	A L	CARBON	53.89	93.01	73.42	69.28	14.2

Total carbon stock

The calculation of the total carbon stock under different land use regimes in the study area depicts that the community forest sequesters greater amount of atmospheric carbon (176. 8 t/ha) than the leasehold forest (155. 18 t/ha) and agricultural land (73. 42 t/ha, Figure 4). However, the difference is not too high which implies that if leasehold forest is well managed, then it possesses potential to sequester greater or equal amount of carbon as sequestered by community forest. Further, comparing only SOC, agricultural land stores higher amount of carbon than the forest. This shows that, agricultural land also contributes significantly in lowering the atmospheric carbon, and carbon sequestration can be increased if farmers are involved in soil and crop management practices.

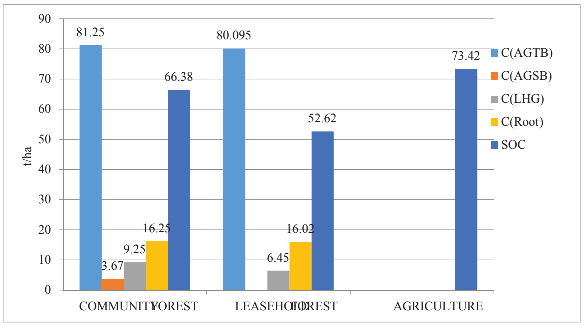

Figure 4 : Total carbon stock in different carbon pools of different land use regimes

Conclusion

As expected, the community forest exhibited higher carbon stock (176. 8 t/ha) followed by leasehold forest (155. 18 t/ha) and agricultural land (73. 42 t/ha). The carbon stored in the forest biomass was found to be 1. 5 times higher than in the forest soils (considering SOC up to 30 cm depth). Although the carbon stock in the community forest was found to be higher than in the leasehold forest, the latter also indicated good potential for enhancing carbon sequestration. This indicates that if proper forest management techniques (proper site preparation, fire management, afforestation, species selection, use of organic fertilizers and manure, application of soil amendments and enforcement of rules and regulations regarding fodder, timber, dead woods and leaf litter collection) are applied by the concerned forest user group, different forest regimes (community forest and leasehold forest) will sequester notable amount of carbon. The highest SOC in the agricultural land indicates that it can contribute significantly in offsetting the carbon emission. In addition, promoting the practice of agroforestry in cropland can further aid in enhancing the carbon capture.

This study can serve as a reference to all the upcoming studies and projects on carbon sequestration for offsetting greenhouse gases to mitigate the impacts of climate change. Further, more detail studies need to be carried out, especially focusing on SOC from depth up to 100 cm, which will aid in more accurate estimation of sequestered carbon. Also studies/researches with focus on particular species (dominant) will serve as a good reference for policy-level to prepare report on offsetting greenhouse gases to be submitted to the international forum on climate change.

References

Acharya, K. P., Dangi, R. B., Tripathi, D. M., Bushley, B. R., Bhandary, R. R. and Bhattarai, B. (eds). 2009. Ready for REDD? Taking stock of experience, opportunities and challenges in Nepal. Nepal Foresters Association, Kathmandu, Nepal.

ANSAB/ICIMOD/NORAD. 2010. Forest Carbon Stock in Community Forests in three Watersheds (Ludhikhola, Kayarkhola and Charnawati). Asia Network for Sustainable Agriculture and Bioresources, International Centre for Integrated Mountain Development, Norwegian Agency for Development Cooperation, Kathmandu, Nepal.

Baral, S. K., Malla, R. and Ranabhat, S. 2009. Above-ground carbon stock assessment in different forest types of Nepal. *BankoJanakari* 19 (2) : 10−14.

Blake, G. R. and Hartage, K. H. 1986. Bulk Density. In *Methods of Soil Analysis, Part I, Physical and Mineralogical Methods* (ed) Klute, A. Madison, Wisconsin, USA : American Society of Agronomy, Soil Science of America.

Canadell, J. G., Le Quéré, C., Raupach, M. R., Field, C. B., Buitenhuis, E. T., Ciais, P., Conway, T. J., Gillett, N. P., Houghton, R. A. and Marland, G. 2007. Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. Proceedings of the National Academy of Sciences of the United States of America. 104 (47) : 18866−18870.

Chan, Y. 2008. Increasing soil organic carbon of agricultural land. PRIMEFACT 735.

Chan, K. Y., Cowie, A., Kelly, G., Singh, B. and Slavich, P. 2008. Scoping paper : Soil organic carbon sequestration potential for agriculture in NSW.

Chave, J., Andalo, C., Brown, S., Caims, M. A., Chambers, J. Q. and Eamus, D. 2005. Tree allometry and estimation of carbon stocks. *Oecologia* 145 (1) : 87−99.

Dahal, N. and Bajracharya, R. M. 2010. Prospects of Soil Organic Carbon Sequestration : Implications for Nepal's Mountain Agriculture. *Journal of Forest and Livelihood* 9 (1) : 45-56.

FAO. 2001. Soil Carbon Sequestration for Improved Land Management. World Soil Resources Report 96. Food and Agriculture Organization, Rome, Italy.

FAO. 2012. State of World's Forest. Food and Agriculture Organization, Rome, Italy.

Lal, R. 2005. Forest soils and carbon sequestration, Forest Ecology and Management. pp 242–258.

Liddicoat, C., Schapel, A., Davenport, D. and Dwyer, E. 2010. PIRSA discussion paper : Soil carbon and climate change. Primary Industries and Resources SA, Prescott Building, Waite Campus, URRBRAE SA 5064.

MacDicken, K. 1997. A guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects Arlington (VA). Forest Carbon Monitoring Program, Winrock International Institute for Agriculture Development.

MoPE/UNEP. 2004. Nepal Initial National Communication to the Conference of the Parties of the United Nations Framework Convention on Climate Change. Ministry of Population and Environment/United Nation Environment Program. Kathmandu, Nepal.

Nelson, D. W., and Sommers, L. E. 1982. Total Carbon, Organic Carbon and Organic Matter. In *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties* (eds) Page, A. L., Miller, R. M. and Keeney, D. R. 2nd edition. American Society of Agronomy Monograph No. 9, ASA-SSSA, Inc., Madison, WI, USA. pp. 539−580.

Oli, B. N. and Shrestha,K. 2009. Carbon Status in Forests of Nepal : An Overview. *Journal of Forest and livelihood* 8 (1) : 63−67. ISSN : 1684–0186.

Pearson, T. R., Brown, S. L., and Birdsey, R. A. 2007. Measurenment Guidelinesfor the Sequestration of Forest Carbon. North Research Station, Department of Agriculture, USA.

Shrestha, B. M. and Singh, B. R. 2007. Soil and vegetation carbon pools in a mountainous watershed of Nepal. *Nutrient Cycling in Agroecosystems* (2008) 81 : 179–191.

Subedi, B. P., Pandey, S., Pandey, A., Rana, E. B., Bhattarai, S., Banskota, T. 2010. Forest Carbon Stock Measurement : Guidelines for measuring carbon stocks in community managed forest. Asia Network for Sustainable Agriculture and Bioresources, International Centre for Integrated Mountain Development, Norwegian Agency for Development Cooperation, Kathmandu, Nepal.

Trumper, K., Bertzky, M., Dickson, B., van der Heijden, G., Jenkins, M., Manning, P. June 2009. The Natural Fix? The role of ecosystems in climate mitigation. A UNEP rapid response assessment. United Nations Environment Programme, UNEPWCMC, Cambridge, UK.

Wutzler, T., Profft, I. andMund, M. 2011. Quantifying tree biomass carbon stocks, their changes and uncertainties using routine stand taxation inventory data. *Silva Fennica* 45 (3) : 359–377.