Global Journal of Science Frontier Research: H
Environment & Earth Science
Volume 15 Issue 3 Version 1.0 Year 2015
Type : Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4626 & Print ISSN: 0975-5896

An Assessment of Carbon Sequestration Ecosystem Service in the Forests of Doon Valley, Western Himalaya, India

By Mohommad Shahid & Shambhu Prasad Joshi
DAV(PG) College, India

Abstract- The study focused on the carbon allocation and carbon sequestration ecosystem service provided by the forests of Doon Valley. 150 Quadrats were laid down to assess the biomass and carbon stocks and the carbon dioxide mitigation potential was estimated in each of the forest ranges (Barkot Range, Lachchiwala Range and Thano Range) of Dehra Dun Forest Division in Doon Valley, Western Himalaya, India. Carbon stock density varies from 13.39 Mg ha^{-1} in Scrub of Thano Range to 213.58 Mg ha^{-1} in Moist Deciduous Forest of Lachchiwala Range. Soil Organic Carbon Density ranged between 161.66 Mg ha^{-1} in Pure Pine Forest of Thano Range to 259.97 Mg ha^{-1} in Moist Deciduous Forest of Barkot Range. Thano Range has the carbon dioxide mitigation share of 37.29% while the Lachchiwala Range shared 35.37%. The Barkot Range contributed 27.34% of the Carbon dioxide mitigation. Various anthropogenic pressures from the villages at the forest fringes have the impact on the carbon stocks. Forests of Doon Valley have the potential to mitigate the climate change through proper and effective implementation of mitigation programmes. Reducing emissions from deforestation and forest degradation plus can be a vital programme that can be implemented to protect the forests of Doon Valley and assist in climate change mitigation.

Keywords: climate change, mitigation, carbon stocks, soil organic carbon, carbon dioxide equivalent, carbon sequestration.

GJSFR-H Classification : FOR Code: 960599

ANASSESSMENTOFCARBONSEQUESTRATIONECOSYSTEMSERVICEINTHEFORESTSOFDOONVALLEYWESTERNHIMALAYAINDIA

Strictly as per the compliance and regulations of :

An Assessment of Carbon Sequestration Ecosystem Service in the Forests of Doon Valley, Western Himalaya, India

Mohommad Shahid [α] & Shambhu Prasad Joshi [σ]

Abstract- The study focused on the carbon allocation and carbon sequestration ecosystem service provided by the forests of Doon Valley. 150 Quadrats were laid down to assess the biomass and carbon stocks and the carbon dioxide mitigation potential was estimated in each of the forest ranges (Barkot Range, Lachchiwala Range and Thano Range) of Dehra Dun Forest Division in Doon Valley, Western Himalaya, India. Carbon stock density varies from 13.39 Mg ha^{-1} in Scrub of Thano Range to 213.58 Mg ha^{-1} in Moist Deciduous Forest of Lachchiwala Range. Soil Organic Carbon Density ranged between 161.66 Mg ha^{-1} in Pure Pine Forest of Thano Range to 259.97 Mg ha^{-1} in Moist Deciduous Forest of Barkot Range. Thano Range has the carbon dioxide mitigation share of 37.29% while the Lachchiwala Range shared 35.37%. The Barkot Range contributed 27.34% of the Carbon dioxide mitigation. Various anthropogenic pressures from the villages at the forest fringes have the impact on the carbon stocks. Forests of Doon Valley have the potential to mitigate the climate change through proper and effective implementation of mitigation programmes. Reducing emissions from deforestation and forest degradation plus can be a vital programme that can be implemented to protect the forests of Doon Valley and assist in climate change mitigation.

Keywords: climate change, mitigation, carbon stocks, soil organic carbon, carbon dioxide equivalent, carbon sequestration.

I. Introduction

Ecosystem functions are the conditions and processes through which natural ecosystems and their constituent species sustain and fulfil human life (Daily 1997). Ecological services are those ecosystem functions that are perceived to support human welfare (De Groot 1992; Ehrlich & Ehrlich 1992; Barbier et al. 1994; Costanza et al. 1997; De Groot et al. 2002). Brown et al. (2006) described Ecosystem Services that are derived from the functioning of an ecosystem and are of direct value to humans.

Forests are very important ecosystems, delivering benefits that go far beyond the supply of timber i.e. fuel wood, fodder, food, bamboos, Non Timber Forest Products (NTFPs), carbon sequestration, climate amelioration, soil and water conservation, recreation, etc. Furthermore, forests play a key role in maintaining water quality, clean air, and help in regulating climate, floods, pollination, biological control of diseases, etc. thus providing various regulating services (Bahuguna and Bisht 2013).

Important climate-related functions of forest ecosystems are carbon sequestration and carbon storage, which create carbon stocks. The persistence and resilience of these carbon stocks as well as the continued ability of forests to absorb carbon dioxide from the atmosphere are significant factors in the role that forests can play in climate change mitigation (Díaz et al. 2009). A rapidly expanding interest in the ability of trees to sequester carbon has spawned numerous initiatives for forest conservation, regeneration and improved management.

Forests sequester and store more carbon than any other terrestrial ecosystem and are an important natural ‘brake’ on climate change. When forest are cleared or degraded, their stored carbon is released into the atmosphere as carbon dioxide (CO_2). The main carbon pools in forest ecosystems are the living biomass of trees and understorey vegetation and the dead mass of litter, woody debris and soil organic matter. Knowledge of the aboveground living biomass density is useful in determining the amount of carbon stored through photosynthesis in the forest stands. Thus, estimating aboveground forest biomass carbon is the most critical step in quantifying carbon stocks and fluxes from forests (Gibbs et al. 2007).

Soil carbon is an important determinant of site fertility due to its role in maintaining soil physical and chemical properties (e.g. aggregate stability, cation exchange capacity) (Reeves 1997). Soil stores 2 or 3 times more carbon than that which exists in the atmosphere (Davidson et al. 2000) as CO_2 and 2.5 to 3.0 times as much as that stored in plants in the terrestrial ecosystem (Houghton and Skole 1990). Land-use and soil-management practices can significantly influence Soil Organic Carbon (SOC) dynamics and C flux from the soil (Batjes 1996; Post & Kwon 2000). Spatially distributed estimates of SOC pools and flux are important requirements for understanding the role of soils in the global C cycle and for assessing potential biospheric responses to climatic change or variation (Schimel et al. 2000).

Author α σ: Ecology Research Laboratory, Department of Botany, DAV (PG) College, Dehra Dun, Uttarakhand, India.
e-mail: mdshahid07@yahoo.com

Various workers have conducted the studies on ecosystem services (Haripriya 2000, 2003; Lead India 2007; Singh 2007; Singh and Das 2008; Gera et al. 2011; Bisht & Singh 2011). In this paper, we analyzed the carbon sequestration service provided by the forests of Doon Valley. Carbon Dioxide mitigation by the forests of Doon valley is worked out.

II. Materials and Methods

a) Study Site

The study was conducted in the three ranges (Barkot Range, Lachchiwala Range and Thano Range) of Dehra Dun Forest Division located in Doon Valley in the Southwestern part of the state of Uttarakhand, India. The word Doon represents the boulder valley that runs parallel to and between the lesser Himalayan range and the Shiwalik range. The Doon valley is located in the Shiwalik Himalayas, lying between latitudes 29°55′ and 30°30′ N and longitudes 77°35′ and 78°24′ E. It is about 20 km wide and 80 km long saucer-shaped valley with a geographical area of ca. 2100 km^2 (Figure 1) The area is bounded by the river Ganga in the east and river Yamuna in the West. The northern boundary is formed by Mussoorie hills whereas the Shiwalik mountains form the southern boundary of the valley. The Doon valley falls under the sub-tropical to temperate climate due to its variable elevation. The average maximum temperature for the Doon valley was 27.65°C and the average minimum temperature was 13.8°C, with average maxima in June (40.00°C) and average minima in January (1.80°C) in year 2010-11. The area received an average annual rainfall of 2025.43 mm. The region receives most of the annual rainfall during June to September, the maximum rainfall occurring in July and August.

b) Biomass Carbon Stock Assessment

50 quadrats of 10 × 10 m^2 were laid down randomly in each range of the entire study area. The height and diameter at breast height (1.37 m above the ground) of all the trees within the sampling quadrat were measured. The volume of the individual trees was estimated using the species specific volume equations (FSI 1996). The estimated volume of each tree was multiplied by its wood density to derive the stem biomass. Later, the bole biomass was multiplied by the biomass expansion factor (Haripriya 2000) to derive individual tree aboveground biomass. Aboveground biomass was used to calculate the Belowground Biomass by multiplying the value of aboveground biomass with the constant factor 0.26 (IPCC 2006). Aboveground biomass and belowground biomass were added to get the individual tree total biomass. The carbon contents was calculated by the multiplying the individual tree total biomass with the conversion factor 0.5 (IPCC 2006). The individual tree total biomass and carbon contents in a quadrat were summed to obtain total biomass and carbon storage in sampling quadrat. The mean total biomass and carbon were calculated by averaging the total biomass and carbon values in all sampling quadrats.

c) Soil Organic Carbon

Soil organic matter tends to concentrate in the upper soil horizons with roughly half of the soil organic carbon of the top 100 cm of mineral soil being held in the upper 30 cm layer (IPCC 2003). Therefore, we have collected the soil samples from the upper 30 cm layer. Forest floor litter was removed and a pit of 30 cm × 30 cm × 30 cm was dugout and soil samples were collected. Soil Organic Carbon was estimated by standard Walkley and Black (1934). Soil Organic Carbon Density (SOCD) was calculated as follows (Ramachandaran et al. 2007).

$$\text{SOCD (Mg ha}^{-1}) = \frac{\text{SOC (\%)} \times \text{CBD (Mg m}^{-3}) \times \text{layer depth(m)} \times 10^4 (\text{m}^2\text{ha}^{-1})}{100}$$

where,
SOCD = Soil Organic Carbon Density
CBD = Corrected Bulk Density

$$\text{CBD (Mg m}^{-3}) = \text{DBD (Mg m}^{-3}) \times \frac{\text{(100- per cent coarse fraction)}}{100}$$

where,
CBD = Corrected Bulk Density (Mg m^{-3})
DBD = Determined Bulk Density (Mg m^{-3})
Total SOC stock = SOC density (Mg ha^{-1}) × forest area (ha).

d) Carbon Dioxide Equivalent (CO_2e)

Sink or sequestration capacity is one of the ecosystem services, provided to us by the natural ecosystems. The carbon dioxide equivalent was calculated as per the following equation:

$$CO_2e \text{ (Mg)} = \text{Carbon Stock (Mg ha}^{-1}) \times 3.66$$

III. Results

a) Biomass Carbon Allocation

The total biomass in Barkot Range was 202.76 Megagram per hectare (Mgha^{-1}) for dry deciduous forest, 329.89 Mgha^{-1} for moist deciduous forest and 293.67 Mgha^{-1} in pure Sal forest. In Lachchiwala Range, total biomass was recorded in the range of 191.40 Mgha^{-1} – 427.16 Mg ha^{-1}. Dry deciduous forest of Lachchiwala Range has the biomass contribution of 191.40 Mgha^{-1} while the moist deciduous forest in Lachchiwala Range was recorded with 427.16 Mgha^{-1}. Pure Sal Forest in Lachchiwala Range has the contribution of 266.04 Mgha^{-1}.In Thano Range, the total biomass was 282.65 Mgha^{-1}, 411.83 Mgha^{-1}, 235.76 Mgha^{-1}, 170.42 Mgha$^{-1,}$ 176.14 Mgha^{-1} and 26.78 Mgha^{-1} for dry deciduous, moist deciduous, pure Sal, pure Pine, degraded forest and scrub respectively.

The carbon stock density in Barkot Range varies from 101.38 Mgha^{-1} to 164.95 Mgha^{-1}. Dry deciduous forest has the contribution of 24.54% while the moist deciduous forest contributed 39.92%. pure Sal forest in Barkot Range shared the contribution of 35.54%. In Lachchiwala Range, the carbon stock density was recorded 95.70 Mgha^{-1} for dry deciduous forests, 213.58 Mgha^{-1} for moist deciduous forests and 133.02 Mgha^{-1} for pure Sal forest. The Thano Range recorded carbon stock density in dry deciduous forest (141.33 Mgha^{-1}), moist deciduous forest (205.92 Mgha^{-1}), pure Sal forest (117.88 Mgha^{-1}), pure Pine (85.21 Mgha^{-1}), degraded forest (88.07 Mgha^{-1}) and Scrub (13.33 Mgha^{-1}).

The total carbon stock in the three ranges was 3446882.72 Mg. The Barkot Range with a forest area of 6109 hectares (ha) has a carbon stock of 918899.76 Mg viz. 97527.56 Mg in dry deciduous forest, 597595.70 Mg in moist deciduous forest while pure Sal forest has 223776.5 Mg Carbon. Moist deciduous forest of Barkot Range has the contribution of 65.03% carbon. Similarly, the Lachchiwala Range recorded 1377647.6 Mg carbon stock in 7711 ha. Dry deciduous forest of Lachchiwala Range contributed 5.86% while the moist deciduous forest contributed 73.79% carbon. Pure Sal forest in Lachchiwala Range has the contribution of 20.33 % carbon. The Thano Range in its 6 forest types covering an area of 11,084 ha pooled 1150335.36Mg carbon. Maximum 47910.08 Mg (45.10%) contribution in Thano Range was by pure Sal forest (Table 1).

b) Soil Organic Carbon

Table 2 reveals the Soil Organic Carbon (SOC) in the different forest types of Study Sites. Barkot Range has the Soil Organic Carbon Density of 209.66 Mgha^{-1} in Dry Deciduous Forest, 259.97 Mgha^{-1} in Moist Deciduous Forest and 172.74 Mgha^{-1} in Pure Sal Forest. Lachchiwala Range was recorded with 177.37 Mgha^{-1} in Dry Deciduous Forest, 228.52 Mgha^{-1} in Moist Deciduous Forest and 186.63Mg ha^{-1} in Pure Sal Forest. Thano Range has 219.43 Mgha^{-1} in Dry Deciduous Forest, 250.07 Mgha^{-1} in Moist Deciduous Forest and 180.90 Mgha^{-1} in Pure Sal Forest. Degraded Forest in Thano Range was recorded with 167.01 Mgha^{-1} of Soil Organic Carbon. Scrub was having 173.06 Mgha^{-1} of Soil Organic Carbon Density. Pure Pine Forest was recorded with 161.66 Mgha^{-1}. The maximum (259.97 Mgha^{-1}) Soil Organic Carbon was recorded in Moist Deciduous Forest of Barkot Range while the minimum 161.66 Mgha^{-1} was recorded from the Pure Pine Forest of Thano Range.

c) Net Carbon Stock

The total biomass carbon of three Ranges of Dehra Dun Forest Division was 3446882.72 Mg and total Soil Organic Carbon was 5058740.50Mg. The ratio between SOC and biomass carbon was 1.47. The carbon content in the soil was higher than the above-ground biomass carbon due to heavy exploitation from the forest. Higher content of Soil Organic Carbon than the aboveground biomass carbon indicates that the sequestered Soil Organic Carbon was the result of its original vegetation in the past before exploitation (Table 3).

d) Carbon Dioxide Mitigation by different forest types

The carbon dioxide mitigation (CO_2 equivalent CO_2e) of different study sites has been presented in Table 3. In Barkot Range, Dry Deciduous forest has the CO_2e of 1138.39 Mgha^{-1} while the moist deciduous forest mitigated 1555.19 Mgha^{-1} CO_2e. Pure Sal Forest of the Barkot Range has the contribution of 1169.64Mg ha^{-1} CO_2e. Dry Deciduous Forest of Lachchiwala Range mitigated 999.42 Mgha^{-1} of CO_2e while the Moist Deciduous Forest mitigated the maximum (1618.08 Mgha^{-1}) of CO_2e. Pure Sal Forest of Lachchiwala Range mitigated 1169.91 Mgha^{-1} of CO_2e. In the Thano Range, Moist Deciduous Forest has the maximum mitigation 1668.938 Mgha^{-1} of CO_2e. Dry Deciduous Forest has the contribution of 1320.36 Mgha^{-1} of CO_2e. Pure Sal Forest in Thano Range contributed 1093.54 Mgha^{-1} of CO_2e mitigation of Carbon Dioxide. 903.55 Mgha^{-1} of CO_2e, 933.59 Mgha^{-1} of CO_2e and 684.61 Mgha^{-1} of CO_2e was mitigated by Pure Pine Forest, Degraded Forest and Scrub respectively. Thano Range has the carbon dioxide mitigation share of 37.29% while the Lachchiwala Range shared 35.37%. The Barkot Range contributed 27.34% of the Carbon dioxide mitigation.

IV. Discussion

The role of forests in harvesting atmospheric carbon has gained considerable importance & debate in recent year. Biomass is an important parameter to assess the atmospheric carbon that is harvested by trees. In recent times, biomass-related studies have become significant due to growing awareness of carbon credit systems the world over.

Sharma et al. (2010) has reported 159.40 $Mgha^{-1}$ in Moist Bhabhar *Shorea robusta* Forest while in present study, 164.95 $Mgha^{-1}$, 213.58 $Mgha^{-1}$, 205.92 $Mgha^{-1}$ of Carbon density was recorded in Moist Deciduous Forest of Barkot Range, Lachchiwala Range and Thano Range respectively. Carbon density (74.50 $Mgha^{-1}$) was reported from dry-sub deciduous forest study conducted by Sharma et al. (2010) while in present study, 101.38 $Mgha^{-1}$, 95.70 $Mgha^{-1}$ and 141.33 $Mgha^{-1}$ Carbon density was recorded in Dry-Deciduous Forest of Barkot Range, Lachchiwala Range and Thano Range respectively. *Pinus roxburghii* has the carbon density of 73.30 $Mgha^{-1}$ (Sharma et al. 2000) while in present study *Pinus roxburghii* forest has the carbon density of 85.21 $Mgha^{-1}$.

Haripriya (2000) reported that above ground biomass had 48.30 $Mgha^{-1}C$ to 97.30 $Mgha^{-1}C$ (approximately 50% of the biomass) in tropical deciduous forests of India. The carbon storage in the present study is much similar to in range as compared to the estimates made in different tropical forests (Atjay et al. 1979; Brown et al. 1994). Based on the growing stock and total area of sal forests in India, Lal and Singh (2003) reported 430.51 $Mgha^{-1}$ average aboveground biomass of tree layer. Similar trends of estimation of Sal forests were also reported by some studies (Negi and Chauhan 2002; Dadhwal et al. 2006). In the Present study, Pure Sal Forest has the Carbon Density of 146.84 $Mgha^{-1}$, 133.02 $Mgha^{-1}$, 117.88 $Mgha^{-1}$ in Barkot Range, Lachchiwala Range and Thano Range respectively. The study site is a natural Sal forest and lopping of trees for fuel and fodder, along with extraction of medicinal (*Zingiber roseum*) and ethanobotanical (*Pterospermum acerifolium*, *Calamus tenuis* etc.) plants are the major disturbances causing the forest degradation and affecting the carbon storage capacity of the forest. In addition to this, in the recent years, over mature Sal, and those infested by *Hoplocerambyx spinicornis* (Sal borers) were also removed by the forest department (Chauhan 2001). Various anthropogenic disturbances prevailing in the study site *viz*. collection of fodder and fuel wood, grazing of cattle, tremendous increase in the population of the Doon Valley has resulted in the forest degradation. The urbanization around the surroundings of the forest has the great impacts on the forest structure. All these disturbances have resulted in large canopy gaps leading to forest degradation.

The results of Soil Organic Carbon density in the present study were also found comparable with earlier studies carried out in Sal forests of Doon Valley. Negi and Chauhan (2002) reported Soil Organic Carbon in Sal forests, varies from 31.0 – 62.90 Mg ha^{-1} in the top 30 cm depth depending upon the tree density and age of the stand tree. They reported highest SOC density (62.9 $Mgha^{-1}$) in 30cm top soil of the Sal forests on flat area in Doon Valley. The highest density of SOC in our study was from Moist Deciduous Forest of Barkot Range, probably due to high density of trees and comparatively less anthropogenic pressure.

The capacity of forest to sequester carbon is a function of the productivity of the site and the potential size of the various pools - soil, litter, down woody material, standing dead wood, live stems, branches, and foliage. Forests play a critical role in regulating the Earth's climate through the carbon cycle; removing carbon from the atmosphere as they grow, and storing carbon in leaves, woody tissue, roots and organic matter in soil. Forests and other terrestrial systems annually absorb approximately 2.6 gigatons of carbon (GtC), or 9.53 gigatons of carbon dioxide equivalent ($GtCO_2e$), while deforestation and degradation of forests emit approximately 1.6GtC (5.87 $GtCO_2e$), for net absorption of 1GtC (3.67 $GtCO_2e$) (IPCC 2007a). Forests therefore play an important role in the global carbon cycle as both a "sink" (absorbing carbon dioxide) and a "source" (emitting carbon dioxide). Total of 31130702 $MgCO_2e$ of Carbon Dioxide was removed by three forest ranges of Doon Valley. Thano Range has the contribution of 11608107 $MgCO_2e$ while the Lachchiwala Range has sequestered 11010428 $MgCO_2e$ of Carbon Dioxide. Barkot Range has sequestered maximum 8512168 $MgCO_2e$ of Carbon Dioxide.

V. Conclusion

The role of forests in preventing and reducing Green House Gases (GHGs) is gaining recognition in market-based policy instruments for climate change mitigation. Climate Change Mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases and forestry sector can play a good role in mitigating the climate change. Forestry is one category of projects that can create carbon dioxide emission reduction credits for trading to offset emissions. Policies governing forest conservation and management are more effective when involving both mitigation and adaptation. Reducing emissions form deforestation and forest degradation (REDD) plus is an approach which can help in the climate change mitigation through (a) conservation of forest carbon stocks, (b) Sustainable management of forest and (c) Enhancement of forest carbon stocks. Properly designed and implemented, forestry mitigation options will have substantial co-benefits in terms of employment and income generation opportunities, biodiversity and watershed conservation, as well as aesthetic and recreational services. Forests of Doon Valley have the potential to mitigate the climate change through proper and effective implementation of mitigation programmes.

VI. Acknowledgement

Authors are thankful to Uttarakhand Forest Department for giving permission to work in the Dehra Dun Forest Division. We also thankful to Forest Research Institute for providing help in the identification of the plants species. We are highly grateful to Mr. V.R.S. Rawat, Scientist E, Biodiversity and Climate Change Division, Indian Council of Forestry Research and Education for his valuable suggestions.

References Références Referencias

1. Atjay G.L., Ketner P., Duvigneaud P., 1979. Terrestrial Primary production and phytomass. In: The Global Cycle. Eds.: Bolin, B., Degens E.T., Kempe S., and Ketner P. John Willey & Sons, Chiester pp. 129-181.
2. Bahuguna V.K., Bisht N.S., 2013. Valuation of Ecosystem Goods and Services from forests in India. Indian Forester 139(1):1-13.
3. Barbier E.B., Burgess J.C., Folke C., 1994. Paradise Lost? The Ecological Economics of Biodiversity. Earthscan Publications Limited. London UK.
4. Batjes N. H., 1996. Total carbon and nitrogen in the soils of the world. European Journal of Soil Science 47:151–163.
5. Bisht N.S., Singh S., 2011. Valuation of Forestry Resources of Manipur. Forest Department Govt. of Manipur. 144pp.
6. Brown S., Therson L.R., Lugo A.E. 1994. Land use and biomass changes of forests in peninsular Malaysia from 1972 to 1982: A GIS approach. Springes-Verlag Jue. U.S.A.
7. Brown T.C., Bergstrom J.C., Loomis J.B., 2006. Ecosystem goods and services: definition, valuation and provision. U.S.D.A. Forest Service, Rocky Mountain Research Station, RMRS-RWU-4851Discussion Paper. 48 pp.
8. Chauhan P. S., 2001. Sal (*Shorea robusta* Gaertn. f.) Mosaic Characterization in Doon Valley. D. Phil. Thesis, Deemed University, Forest Research Institute, Dehra Dun, India.
9. Costanza R., Cumberland J., Daly H., Goodland R., Norgaard R., 1997. An Introduction to Ecological Economics St. Lucie Press, Boca Raton, Florida, USA.
10. Dadhwal V.K., Kushwaha S.P.S., Singh I.J., Nandy S., Mukhopadhyay S., Pandey U., 2006. Understanding terrestrial carbon cycle in India using remote sensing. Proc. Indo-UK Workshop on Earth Observations for Weather and Climate, 28-30 March, 2006, SAC, Ahmedabad.
11. Daily G.C., 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Washington, DC, USA: Island Press.
12. Davidson E. A., Trumbore S. E., Amudson R., 2000. Soil warming and organic carbon content. Nature 408:789–790.
13. De Groot R.S., 1992. Functions of Nature: Evaluation of Nature in Environment Planning, Management and Decision Making. Groningen, The Netherlands: Wolters Noordhoff BV.
14. De Groot R.S., Wilson M.A., Boumans R.M.J., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41(3): 393–408.
15. Díaz S., Hector A., Wardle D.A., 2009. Biodiversity in forest carbon sequestration initiatives: not just a side benefit. Current Opinion in Environmental Sustainability 1(1): 55–60.
16. Ehrlich P.R., Ehrlich A.E., 1992. The value of biodiversity. Ambio 21: 219–226.
17. FSI (Forest survey of India) 1996.Volume Equations for Forests of India, Nepal and Bhutan. Forest survey of India, Ministry of Environment and Forests, Dehra Dun, India.
18. Gera N., Gera M., Bisht N.S., 2011. Carbon sequestration potential of selected plantation interventions in Terai region of Uttarakhand. Indian Forester 137(3):273-289.
19. Gibbs H.K., Brown S., Niles J.O., Foley J.A., 2007. Monitoring and estimating tropical forest carbon stocks: making REDD a reality. Environmental Research Letters 2 045023 1-13.
20. Haripriya G. S., 2000. Estimates of biomass in Indian forests. Biomass and Bioenergy Vol.19 (4): 245-258.
21. Haripriya G.S., 2000. Integrating forest resources into the system of national accounts in Maharashtra, India. Environment and Development Economics 5(1): 143-156.
22. Haripriya G.S., 2003. Carbon budget of Indian forests. Climatic Change 56(3): 291-319.
23. Houghton R.A., Skole D.L., 1990. Carbon In: The Earth as Transformed by Human Action (eds B. L. Turner, W. C. Clark, R. W. Kates, J. F. Richards, J. T. Matthews, & W. B. Meyer). Cambridge University Press, Cambridge, New York, pp. 393–408.
24. IPCC, 2007a. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M., Miller H.L., (Eds.)], Cambridge University Press, Cambridge, United Kingdom and New York, USA.
25. IPCC., 2006. IPCC Guidelines for National Greenhouse Gas Inventories Volume 4: Agriculture, Forestry and Other Land Use. IPCC/IGES, Hayama, Japan.
26. IPCC., 2003. Good Practice Guidance for Land Use, Land Use Change and Forestry Published by the

Institute for Global Environmental Strategies (IGES) for the IPCC. Publishers Institute for Global Environmental Strategies, Japan.
27. Kumar P., 2004. Economics of soil erosion: issues and imperative from India. Concept Publishing Company, New Delhi. 181 pp.
28. Lal A.K., Singh P.P., 2003. Economic worth of carbon stored in aboveground biomass of India's forests. Indian Forester 129(7) 874-880.
29. Lead India, 2007. Valuation of Ecosystem Services and Forest Governance: A Scoping Study from Uttarakhand. Lead India, New Delhi.
30. Negi J.D.S., Chahaun P.S., 2002. Green House Gases (GHGs) Mitigation Potential by Sal (*Shorea robusta* Gaertn .f.) Forest in Doon Valley. Indian Forester 128 (7):771-778.
31. Post W. M., Kwon K.C., 2000. Soil carbon sequestration and land-use change: Processes and potential. Global Change Biology 6:317–327.
32. Ramachandran A., Jayakumar S., Haroon R.M., Bhaskaran A., Arockiasamy D.I., 2007. Carbon sequestration: estimation of carbon stock in natural forests using geospatial technology in the Eastern Ghats of Tamil Nadu, India. Current Science Vol. 92 No.3. 323-331.
33. Reeves D. W., 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil & Tillage Research.43:131–167.
34. Schimel D. et al., 2000. Contribution of increasing CO_2 and climate to carbon storage by ecosystems in the United States. Science 287:2004–2006.
35. Sharma C.M., Baduni N.P., Gairola S., Ghilidiyal S.K., Suyal S. 2010. Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India. Forest Ecology Management 260(12):2170-2179.
36. Singh J.K., Das D.K., 2008. Environmental Economics and Development. Deep and Deep Publication Pvt. Ltd. New Delhi.
37. Singh S.P., 2007. Himalayan Forest: Ecosystem Services. Incorporating in national accounting Kyoto: Think Global, Act Local. Central Himalayan Environment Association, Nainital, Uttarakhand.
38. Walkley A., Black I.A., 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science 37, 29–38.

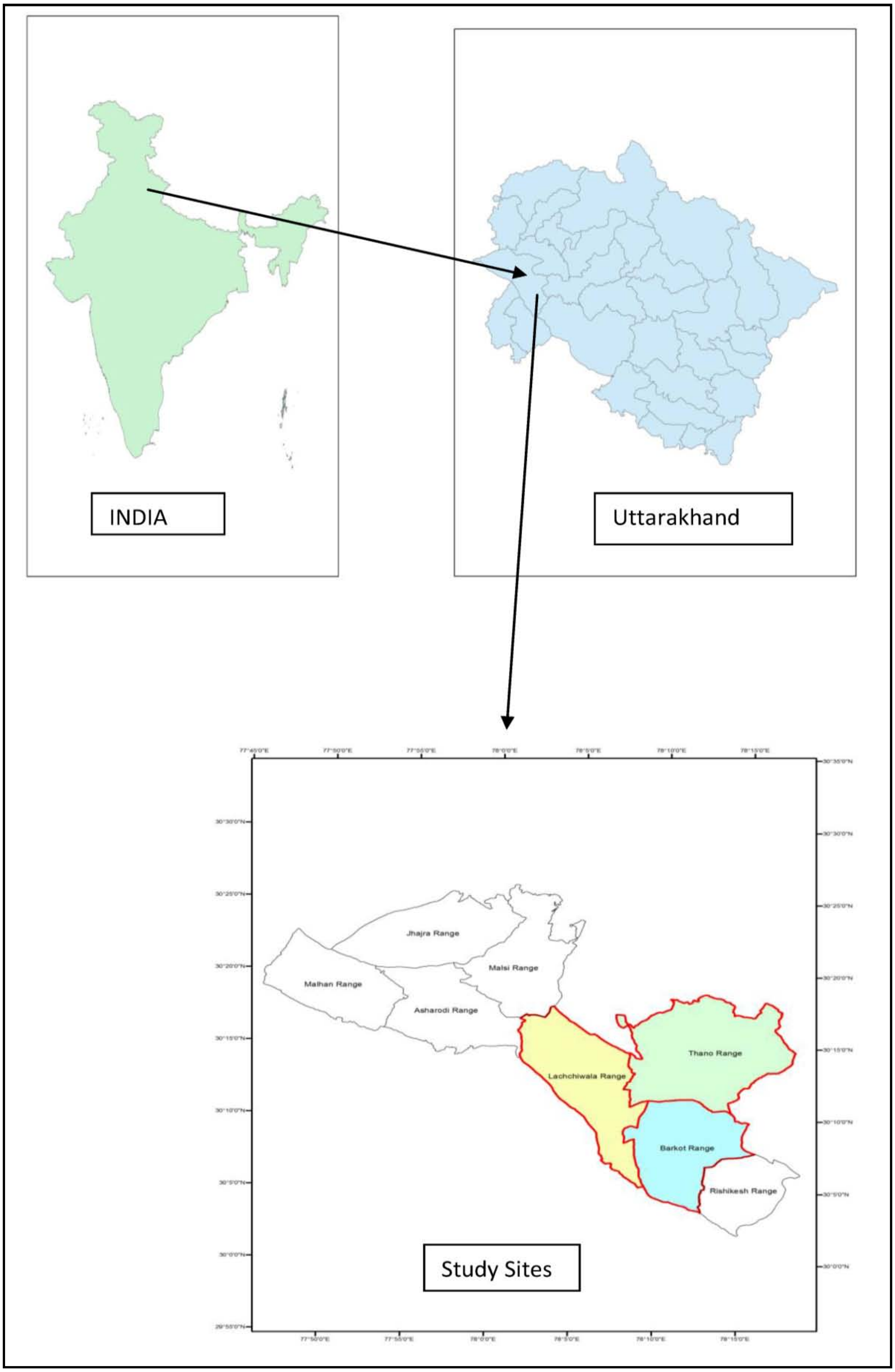

Figure 1 : Location of the study sites

Table1 : Biomass and Carbon Stock in the forests of Doon Valley

Study Site	Forest Type	Area (ha)	Total Biomass Density ($Mgha^{-1}$)	Carbon Density ($Mgha^{-1}$)	Carbon Stock (Mg)
Barkot Range	Dry Deciduous Forest	962	202.76	101.38	97527.56
	Moist Deciduous Forest	3623	329.89	164.95	597595.7
	Pure Sal Forest	1524	293.67	146.84	223776.50
Lachchiwala Range	Dry Deciduous Forest	845	191.40	95.70	80866.50
	Moist Deciduous Forest	4760	427.16	213.58	1016641.00
	Pure Sal Forest	2106	266.04	133.02	280140.10
Thano Range	Dry Deciduous Forest	325	282.65	141.33	45930.63
	Moist Deciduous Forest	1198	411.83	205.92	246686.20
	Pure Sal Forest	4402	235.76	117.88	518907.80
	Pure Pine Forest	3190	170.42	85.21	271819.90
	Degraded Forest	544	176.14	88.07	47910.08
	Scrub	1425	26.78	13.39	19080.75

Table 2 : Soil Organic Carbon Stock in the forests of Doon Valley

Study Site	Forest Type	Soil Organic Carbon Density ($Mgha^{-1}$)	Carbon Stock (Mg)
Barkot Range	Dry Deciduous Forest	209.66	201691.00
	Moist Deciduous Forest	259.97	941862.25
	Pure Sal Forest	172.74	263250.12
Lachchiwala Range	Dry Deciduous Forest	177.37	149875.37
	Moist Deciduous Forest	228.52	1087749.49
	Pure Sal Forest	186.63	393041.31
Thano Range	Dry Deciduous Forest	219.43	71313.19
	Moist Deciduous Forest	250.07	299588.65
	Pure Sal Forest	180.90	796338.09
	Pure Pine Forest	161.66	515708.16
	Degraded Forest	167.01	90853.82
	Scrub	173.66	247469.06

Table 3 : Net Carbon Stock and Carbon dioxide mitigation by the forests of Doon Valley

Study Site	Forest Type	Net Carbon Stock (Mg)	CO2e ($Mgha^{-1}$)	Total CO_2e (Mg)
Barkot Range	Dry Deciduous Forest	299218.56	1138.39	1095139.9
	Moist Deciduous Forest	1539476.10	1555.19	5634482.5
	Pure Sal Forest	487034.28	1169.64	1782545.5
Lachchiwala Range	Dry Deciduous Forest	230741.87	999.42	844515.24
	Moist Deciduous Forest	2104390.29	1618.08	7702068.5
	Pure Sal Forest	673181.43	1169.91	2463844
Thano Range	Dry Deciduous Forest	117245.44	1320.36	429118.31
	Moist Deciduous Forest	546280.81	1668.94	1999387.8
	Pure Sal Forest	1315245.85	1093.54	4813799.8
	Pure Pine Forest	787528.06	903.55	2882352.7
	Degraded Forest	138763.90	933.59	507875.88
	Scrub	266549.81	684.61	975572.31

This page is intentionally left blank