Carbon sequestration potential of *Alnus nepalensis* in the mid hill of Nepal: A case study from Kaski district

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This study was carried out to analyze the carbon content in different parts of *Alnus nepalensis*, and to assess the effect of aspect and altitude in the carbon storage in *Alnus nepalensis* as well as to quantify the total carbon sequestration (stock) in *Alnus nepalensis* forest in the mid-hills of Kaski District. The inventory for estimating above and below ground biomass of forest was carried out using stratified random sampling technique. The carbon content in different parts of *Alnus nepalensis* was quantified using combustion method in the laboratory. For determining the soil carbon content, six soil profiles from each aspect were excavated and soil samples were taken from soil profile up to 1 m depth for deep soil and up to bedrock for shallow soils at the interval of 20 cm. Mean carbon content in stem, branches, leaves and bark of *Alnus nepalensis* were found to be 40.52%, 33%, 9.56% and 16.4%, respectively. Total biomass carbon sequestered in northern aspect was 30.20 t/ha while for southern aspect it was 39.00 t/ha. In both the aspects higher carbon sequestration was observed at an elevation range of 1200-1300m i.e. 34.8 t/ha and 45.6 t/ha in northern and southern aspects, respectively. Soil carbon sequestration in northern and southern aspects was found to be 113.4 t/ha and 169.30 t/ha, respectively. The total carbon sequestration potential of *Alnus nepalensis* forest was estimated to be 186.05 t/ha.

Key words: *Alnus nepalensis*, altitude, aspect, carbon sequestration, mid hills

Drastic climate change and the escalating trend of the global warming have been triggered by human activities leading to elevated atmospheric carbon and greenhouse gas levels. Such change is unlikely to have occurred through natural forces alone. The biggest factor of present concern is the increase in CO_2 levels due to emissions from fossil fuel combustion, followed by aerosols (particulate matter in the atmosphere) which exert a cooling effect and cement manufacture. Other factors, including land use, ozone depletion, animal agriculture, deforestation and land use change also impact climate.

To control global warming there are many options such as the mitigative option- sequestration of CO_2 and reduction of emission; the adaptive option – adjustment in ways that reduce the negative impacts of temperature changes on the environment; and indirect policies - like controlling population growth or changing technologies. Among the options, forestry is one of the most cost-effective mitigating options (IPCC, 1995). Forests cover more than one third of the world's land area and constitute the major terrestrial carbon pool (Mellillo et al, 1990; Roberntz et al, 1999). Carbon (C) storage in forest ecosystems involves numerous components including biomass C and soil C.

Thus, in addition to various goods and services being provided to human beings, forests act as a natural storage for carbon at the global scale, contributing approximately 80% of terrestrial aboveground, and 40% of terrestrial belowground carbon storage (Kirschbaum, 1996). Overall, forest ecosystems store 20–100 times more C per unit area than croplands and hence play a critical role in reducing ambient CO_2 levels, by sequestering atmospheric C in the growth of woody biomass through the process of photosynthesis and thereby increasing the soil organic carbon (SOC) content (Brown and Pearce, 1994).

The main reason for forestry being of high interest is the flexibility provided by increased stocks of C in forests under the uncertainty regarding the impact of global warming (Solberg, 1997). Recognizing the importance of forest and soil in mitigating the greenhouse effect, an agreement was reached under the Kyoto Protocol (KP) to include forest and soil C

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sequestration in the list of acceptable offsets (UNFCCC, 1997). KP under the UNFCC links the environment with economy by establishing a global Carbon market. To implement KP, Clean Development Mechanism (CDM) is only flexible way that allows developing countries to participate in the emerging global climate market. The CDM allows industrialized counties to meet their emission reduction targets through projects in developing countries like Nepal, which contributes little to global warming. CDM has dual objectives of sustainable development and emission reduction (Sharma et al, 2004).

It is assumed that fast growing trees like *Alnus nepalensis* fix the atmospheric carbon in above and below ground biomass more rapidly compared to slow growing species. However, the actual carbon sequestration potentiality of *Alnus nepalensis* has not so far been assessed in mid hills of Nepal. The mid-hills of Nepal consist of large forest tracts of *Alnus nepalensis* at different elevations and aspects, which requires assessment of total carbon sequestration potential of such forest. Therefore, this study aims to establish the base line information for carbon sequestration potential of *Alnus nepalensis* forest at different elevation ranges and aspects.

Materials and methods

Study area

The study was carried out in Kaski district which is located on the western part of Nepal. It lies between the 83^o 40' to 84^o 12' latitude and 28^o 6' to 28^o 36' longitude and is at 200 km distance west of the capital. The elevation varies from 450 m to 7969 m from mean sea level. Due to variation in landscape and altitude, the climate and natural vegetation of the district varies with a great influence of the monsoon. Range of rainfall varies from minimum 3038 mm to 3353.3 mm. Similarly, temperature is maximum in April up to 33^o C and minimum in January up to 5.6^o C.

Sampling

Three sample plots of 20 m by 25 m were laid randomly in each site at different elevation ranging from (1000-1600 m) and two aspects (north and south) for collecting data. The quadrates of size 10m x 10m for poles, nested quadrates of size 1m x1m for regeneration, grass and herb were laid out, and measurement of individual trees/poles lying within the plots were taken.

Biophysical measurements:

Measurement of diameter at breast height (dbh) within each plot was the main biophysical measure. D-tape was used for measuring dbh.

Estimation of carbon content in different parts of *Alnus nepalensis*

Four samples of each stem, branch and leaf were collected during field visit. The samples were oven dried at 75 degree centigrade for 72 hours. Then, it was heated in muffle furnace at 400 ^{0}C for half an hour. The organic carbon contain of the samples was determined using following relations (Negi et al, 2003)

Carbon% = 100 - {ash weight + molecular weight of O_2 (53.3) in $C_6H_{12}O_6$} .... (i)

Estimation of aboveground biomass

For estimating, the oven dry biomass of the tree components following biomass model was used

$\ln (W) = a + b*\ln (d)$ .... (ii)

Where, W= is above ground oven dry biomass of tree (kg),

d = is the diameter at breast height (cm), and

a, b = are parameters estimated by MoFSC (1996) (see Table1).

Under growth biomass:

All under storey bushes, grasses and herbaceous layers within the nested quadrate were clipped and weighed. Clipped samples were sun dried for 3- 5 days. In addition, leaf litters and twigs within the quadrate were collected separately and sun dried and weighed.

Root biomass

It is also necessary to calculate the root biomass as roots play an important role in the carbon cycle as they transfer considerable amounts of C to ground,

Table 1: The estimated values of parameters (a and b) for the tree species

Species Parts	Alnus nepalensis		Schima wallichi		Castonopsis indica	
	a	b	a	b	a	b
Stem	-2.95	2.48	-2.78	2.23	-1.78	1.99
Branch	-4.44	2.36	-3.43	1.59	-2.14	1.40
Leaves	-4.77	2.23	-2.90	1.61	-1.63	1.45

where it may be stored for a relatively long period. However, the measurement of root biomass directly in the field is not a simple task. It requires a lot of time as well as experience, and therefore used the equation that has already been established.

For broad leaf vegetation,
Belowground biomass = 30% of aboveground biomass .... (iii)
(Adopted from: Nepal, 2006)

Estimation of net carbon content

Carbon percent obtained from the equation (i) was used for the computing carbon content in stem, branches and leaves, which is 40.52%, 33% and 9.56% respectively.

While the carbon content for the understorey biomass was assumed 43% of dry biomass (Maclaren-Ford Robertson, 2001). The equations used for above and below ground biomass organic carbon are:

- Total above ground biomass organic carbon = {(total stem biomass * 40.52%) + (total branches biomass * 33%) + (total leaves biomass * 9.56%) + (total twig and litter biomass * 43%)} ...... (iv)
- Total below ground organic carbon = (total root biomass of tree) * 40.52% + total soil organic carbon .... (v)

Soil Sampling

Soil samples were taken from soil profile up to 1m depth for deep soil and up to the bed rock for shallow soils at five different levels (0-20cm, 20-40cm, 40-60cm, 60-80cm, 80-100cm). A profile was dug at least six places in each aspect and soil samples was collected at above stated intervals and transported to laboratory for analysis.

Bulk density (BD):

Soil cores of 4 cm in diameter and 10 cm long was used for collecting the bulk density data of each soil layer. The weight of soil samples were measured after oven drying 24 hours at constant temperature of 105 ^{0}C in the laboratory.

BD = (Oven dry weight of soil) / (Volume of the soil) .... (vi)

BD expressed in gm/cm^3

Soil organic carbon (SOC):

The Walkey-Black method (Jackson, 1958) was applied to measure the soil organic carbon percent. Total soil organic carbon was calculated using the formula given below. (Chabbra et.al, 2002):
SOC = Organic carbon content%*soil bulk density (kg/m^3)*thickness of horizon (m)

Further, it was expressed in t/ha

Results and discussion

Carbon content in different parts of *Alnus nepalensis*

Carbon content was found higher in the stem part i.e 40.52% and low in the leaves i.e 9.56%. Similarly, carbon content in the branches and barks were 33% and 16.41% respectively (Table 2). Carbon content was found higher in stem due to the higher density compared to leaves.

Table 2: Carbon content in different parts of *Alnus nepalensis*.

Name of parts	Sample No.	Mean Carbon %	SE Mean
Under stem	8	40.52	0.84
Leaves	4	9.56	0.38
Branches	4	33.00	0.40
Barks	4	16.41	2.85

Note SE: Standard Error

Estimation of biomass of tree:

The biomass of *Alnus nepalensis* varies with elevation range and aspects. In Northern aspect, higher biomass was found at the elevation range 1200-1300 m i.e. 4.596 t/plot while lower at the elevation range 1000-1100 m i.e. 2.604 t/plot. Similarly, higher biomass was found at the elevation range 1200-1300m i.e. 5.980t/plot while lower at the elevation range 1400-1500 m i.e 4.490 t/plot in Southern aspect. Thus, Southern aspect has 1.29 times higher biomass compared to Northern aspect. Difference in biomass at different elevation was due to the moisture content, soil property, temperature, duration of sunlight available and steepness of slope. Biomass was higher on Southern aspect than Northern aspect (Table 3 and 4) because the duration of sunlight is higher in Southern aspect, which directly promotes more photosynthesis than the Northern aspect. Therefore, the net primary productivity was found higher in Southern aspect forest. In both the aspect biomass was found in increasing order up to middle elevation range and than gradual decrease because with the increase in altitude the SOC and temperature decreases.

Table 3: Aboveground biomass in Northern aspect

Elevation Range	Mean(t/plot)	SE mean	Minimum	Maximum	Range	No. of plots
1000-1100	2.604	0.121	2.162	3.038	0.875	6
1100-1200	3.917	0.710	2.338	7.150	4.810	6
1200-1300	4.596	0.453	3.566	6.100	2.534.	6
1300-1400	4.396	0.863	2.814	8.407	5.593	6
1400-1500	4.330	0.253	3.357	5.040	1.682	6
1500-1600	4.288	0.854	2.152	8.151	5.998	6
	Mean above ground biomass		4.022 t/plot			

Table 4: Aboveground biomass in Southern aspect

Elevation Range	Mean (t/plot)	SE mean	Minimum	Maximum	Range	No. of plots
1000-1100	4.514	0.573	3.040	6.542	3.502	6
1100-1200	5.408	1.387	1.660	9.756	8.096	6
1200-1300	5.980	1.273	2.761	1.046	7.702	6
1300-1400	5.640	0.719	3.467	8.435	4.967	6
1400-1600	4.490	0.684	2.576	6.636	4.059	6
1500-1600	4.808	0.860	3.084	8.990	5.902	6
	Mean above ground biomass: 5.140 t/plot					

Note: t = ton, SE = standard error

Above ground carbon sequestration

It was found that above ground carbon sequestration was higher in Southern aspect than in Northern aspect (Table 5 and 6). The above ground carbon sequestration in Northern aspect and Southern aspect forests including *Alnu*s *nepalensis*, *Castonopsis indica* and *Schima wallich*i was found 30.20 t/ha and 39.00 t/ha respectively. Similarly, in both the aspect higher carbon sequestered was observed at the middle range elevations (Fig 1). With the increase in the elevation, the carbon sequestration potential was found to decrease because temperature decreases as altitude increases.

During photosynthesis, carbon from the atmospheric CO_2 incorporates into products of organic compounds. All the organic compounds containing carbon are stored in different plant tissues as food. Thus, carbon appears as a part of plant biomass. The total aboveground organic carbon includes carbon on the aboveground tree biomass (eg. branch, stem), litter fall, twigs and biomass of undergrowth (Gautam, 2002).

Table 5: Above ground carbon sequestration in Northern aspect

Elevation Range	CS by				Total above ground CS	
	Stem	Branch	Leaves	Undrestorey	(t/plot)	(t/ha)
1000-1100	0.862	0.105	0.015	0.00012	0.982	19.64
1100-1200	1.310	0.150	0.022	0.00013	1.482	29.64
1200-1300	1.535	0.180	0.025	0.00014	1.740	34.80
1300-1400	1.474	0.172	0.023	0.00014	1.670	33.50
1400-1500	1.377	0.171	0.024	0.00015	1.572	31.40
1500-1600	1.431	0.168	0.023	0.00015	1.623	32.46
	Mean above ground Carbon Sequestration: 30.20 t/ha					

Table 6: Above ground carbon sequestration in Southern aspect

Elevation Range	CS by				Total above ground CS	
	Stem	Branch	Leaves	Understorey	(t/plot)	(t/ha)
1000-1100	1.539	0.182	0.016	0.000144	1.737	34.74
1100-1200	1.815	0.207	0.028	0.000164	2.051	41.22
1200-1300	2.009	0.234	0.030	0.000173	2.273	45.46
1300-1400	1.890	0.221	0.290	0.000180	2.140	42.98
1400-1500	1.497	0.180	0.024	0.000183	1.701	34.02
1500-1600	1.610	0.190	0.025	0.000181	1.825	36.50
	Mean above Carbon Sequestration: 39.00 t/ha					

Note: t = metric ton, CS = Carbon Sequestration

Higher carbon sequestration may be attributed by the fact that Southern aspect has higher biomass compared to Northern aspect. In Southern aspect duration of sunlight is longer compare to Northern aspect, which directly affects the photosynthesis. Therefore, the net primary productivity was found higher in southern aspect forest. In both aspects, higher carbon sequestration was in elevation range 1200-1300 m due to the dense biomass of the forest. It was found the lowest carbon sequestration in the southern aspect at the elevation range 1400-1500 m due to steepness of slope, which has affected the soil depth hence the root development. And in Northern aspect lower carbon sequestration was found at the elevation range 1000-1100 m, which lies near the river, and soil condition at that site was poor due to stoniness in the soil.

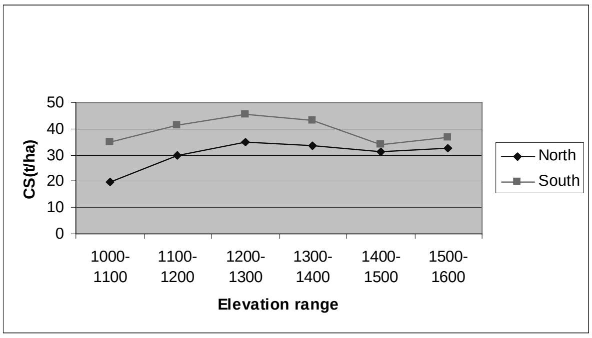

Figure1: Above ground carbon sequestration in *Alnus nepalensis*

Root carbon sequestration

Root carbon sequestration in the two aspects is shown in Table 7. The carbon content was calculated after calculating the root biomass assuming root biomass is 30 % of above ground biomass and the carbon content of roots is to be 40.52 % (table 2) of the calculated biomass. The total root carbon sequestration of *Alnus nepalensis* including the *Castonopsis indica and Schima wallichi* species for the Northern and Southern aspects of the forests was 8.191 t/ha and 12.500 t/ha, respectively. Similarly the higher root carbon sequestration was found at the elevation range 1200-1300 m i.e. 11.170 t/ha and 14.530 t/ha in both Northern and Southern aspect respectively. The higher value of root carbon sequestration in the Southern aspect forest at the elevation range1200-1300 m may be attributed to the higher above ground biomass and dense vegetation in the forest.

Soil Carbon sequestration:

Bulk density (Bd)

The range of bulk density in *Alnus nepalensis* forest based on the entire profile (0-100m) depths is shown in (Table 8). There was large variation in the Bd with respect to depth in the forest soils. There was a gradual increase in the Bd with the increase in the soil depth in both aspect The minimum Bd i.e 1.131 gm/cm^3 was found at the top soil while maximum 1.473 gm/cm^3 at the depth of 80-100cm in northern aspect. Similarly, in southern aspect minimum bulk density was found at top soil i.e. 1.007 gm/cm^3 and maximum at the depth of 80 – 100 cm i.e. 1.277 gm/cm^3.

The Bd depends on several factors such as compaction, consolidation and amount of SOC present in the soil but it is highly correlated to the organic carbon content (Morisada et al, 2004, Leifeld et al, 2004).

Table 7: Root carbon sequestration

Elevation Range	North			South		
	Root biomass(t/ha)	CS		Root biomass(t/ha)	CS	
		(t/plot)	(t/ha)		(t/plot)	(t/ha)
1000-1100	0.781	0.316	6.330	1.354	0.549	10.974
1100-1200	1.175	0.476	9.520	1.623	0.657	13.150
1200-1300	1.380	0.558	11.170	1.794	0.727	14.53
1300-1400	1.319	0.534	10.690	1.692	0.685	13.714
1400-1500	1.300	0.526	10.535	1.347	0.546	10.918
1500-1600	1.286	0.521	10.424	1.442	0.584	11.700
Mean root carbon sequestration		8.191 t/ha		12.500 t/ha		

Note: t = metric ton, CS = Carbon Sequestration

Table 8: Aspect wise bulk density at different depths

Depth	Northern aspect		Southern aspect	
	Mean (g/cm^3)	SE Mean	Mean (g/cm^3)	SE Mean
0-20	1.131	0.083	1.007	0.068
20-40	1.219	0.969	1.101	0.126
40-60	1.353	1.124	1.117	0.051
60-80	1.473	0.000	1.277	0.361

Note: SE = Standard Error

Table 9: Carbon stock in different soil profile depths of two aspect forests

Depth	Northern			Southern		
	N	Mean(kg/sq.m)	SE Mean	N	Mean(kg/sq.m)	SE Mean
0-20	6	3.67	0.97	6	4.33	0.67
20-40	6	2.77	0.69	6	3.61	0.51
40-60	6	1.85	0.42	6	3.58	0.84
60-80	1	1.65	0.00	2	3.07	0.27
80-100	1	1.40	0.00	2	2.34	0.30

Soil organic carbon

The soil organic carbon in forest soil depends upon the forest type, climate, moisture, temperature and types of soil.

Table 9 shows the depth wise distribution of SOC stock in the forests. Multiple comparison of means revealed that the SOC was higher at the upper layers in both the forest. Maximum SOC value 4.33 kg/sq.m was found at top layer while miminum 2.34 kg/sq.m was found at the lower depth in Southern aspect. In Northern aspect 3.67 kg/sq.m and 1.40 kg/sq.m was found at top and bottom layers. Thus, it was found that there was effect of soil depth and aspect on SOC.

The mean value of the sum of soil carbon sequestration in all layers along the soil profile is shown in Table 10. The carbon sequestration in the soil from the top layer of 0-20cm to 80-100cm depth for Northern aspect forest was found to be 11.34 kg/m2 and that of Southern aspect forest was 16.93 kg/m2 .Total SOC in Northern and Southern aspect forest was found to be 113.40 t/ha and 169.30 t/ha respectively. The actual soil organic carbon sequestration by *Alnus nepalensis* could not be analyzed due to lack of base line data of soil organic carbon in the study site. Therefore, the total soil organic carbon content is considered as the soil carbon sequestration.

Table 10: Soil Carbon sequestration in the two aspect forests

Aspect	Sum CS in all layers (kg/sq.m)	Tons/ha
Northern	11.34	113.40
Southern	16.93	169.30

Total carbon sequestration by *Alnus nepalensis*

The total carbon sequestration in the *Alnus nepalensis* forests is shown in Table 11. The total carbon sequestration was the sum of aboveground, root and soil carbon. Total carbon sequestration in *Alnus nepalensis* forest was found to be 151.80 t/ha in Northern aspect while 220.30 t/ha in Southern aspect. Mean carbon sequestration in *Alnu*s *nepalensis* forest in both aspect was found to be 186.05 t/ha. Pinus and *Alnu*s *nepalensis* are the fast growing soft wood so data was compared with Pinus. Above ground carbon sequestration and root carbon sequestration was found higher in *Alnus nepalensis* than in Pinus forest study of which was done in past by Nepal, 2006 at Palpa district. However, the carbon sequestration in soil was found lower compared to Pinus sps, which is attributed by the fact that *Alnus nepalensis* found in less fertile soil. It rapidly colonizes the gravelly land exposed by landslides and old cultivated land (Jacksons, 1994)

Carbon sequestration potential of *Alnus nepalensis* forest was found 76 percent in soil, while 19 percent in aboveground biomass and 5 percent in underground biomass. (Fig 2)

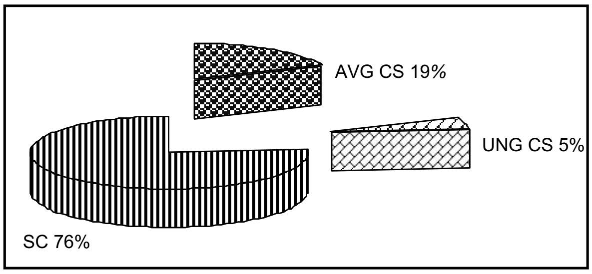

Fig 2: Carbon Sequestration in *Alnus nepalensis* forest

Table 11: Total carbon sequestration in *Alnus nepalensis* forest

SN	Carbon sequestration in	CS in northern aspect (t/ha)	CS in southern aspect (t/ha)
1	Above ground	30.20	39.00
2	Root carbon	8.19	12.00
3	Soil carbon	113.40	169.30
Total		151.80	220.30
Mean carbon sequestration by *Alnus nepalensis* forest of both aspect		186.05 t/ha	

Note: AVG CS = Above ground carbon sequestration,
UNG CS = Under ground carbon sequestration, SC = Soil carbon

Conclusion

- The above ground carbon sequestration in *Alnus nepalensis* forest in southern aspect was found 1.29 times higher than northern aspect of the same forest.
- The below ground carbon sequestration for southern aspect was found 1.49 times higher than northern aspect of the forest.
- Soil carbon sequestration was found 3 times as higher as total biomass carbon sequestration in *Alnus nepalensis*
- Carbon sequestration potential was found higher in both aspects of middle altitude as compared to lower and higher altitude.
- Bulk density increases while SOC decreases with the depth of the soil in both aspects.

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