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Stand Structure, Productivity and Carbon Sequestration Potential of Oak Dominated Forests in Kumaun Himalaya

BIJENDRA LAL and L.S. LODHIYAL

Department of Forestry and Environmental Science, D.S.B. Campus, Kumaun University, Nainital-263002, Uttarakhand india.

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ABSTRACT

Present study deals with stand structure, biomass, productivity and carbon sequestration in oak dominated forests mixed with other broad leaved tree species. The sites of studied forests were located in Nainital region between $29^0 58'$ N lat. and $79^0 28'$ E long at 1500-2150 m elevation. Tree density of forests ranged from 980-1100 ind.ha^{-1}. Of this, oak trees shared 69-97%. The basal area of trees was 31.81 to 63.93 m^2 ha^{-1}. *R. arboreum and Q. floribunda* shared maximum basal area 16.45 and 16.32 m^2 ha^{-1}, respectively in forest site-1 and 2 while *Quercus leucotrichophora* shared maximum (35.69 m^2 ha^{-1}) in site-3. The biomass and primary productivity of tree species ranged from 481-569 t ha^{-1} and 16.9-20.9 t ha^{-1}yr^{-}1, respectively. Of this, biomass and primary productivity of oak tree species accounted for 81 to 95 and 78 to 98%, respectively. Carbon stock and carbon sequestration ranged from 228 to 270 t ha^{-1} and 8.0 to 9.9 t ha^{-1}yr^{-1}, respectively. The share of oak tree species ranged from 81 to 94.7 and 79 to 97%, respectively. The diversity of tree species ranged from 0.03 to 0.16 in forest sites-1, 2 and 3. The diversity of oak species was 0.08-0.16 in all the forest sites. Thus it is concluded that among the oak tree species, *Quercus floribunda* and *Quercus leucotrichophora* were highly dominated in the studied forests. The climax form of oak dominated trees in the studied forest sites depicted slightly lower richness and diversity of tree species compared to the forests in the region and elsewhere. As far as dry matter and carbon of forests is concerned, these estimates are close to the earlier reports of forests in the region. Therefore, studied forests have the potential to increase the diversity, productivity and carbon sequestration of forest tree species by providing the adequate scientific conservation and management inputs.

Keywords: Vegetation Analysis, Biomass, Productivity, Carbon, Sequestration, Kumaun Himalaya.

INTRODUCTION

Stand structure significantly determines the aspects of dry matter productivity and carbon potential of forest in each site. However, the productivity of forests not only depends on stand structure and composition of forest but also impacted by several other factors such as climate, soil condition, availability of moisture, and conservation and management practices. In this regard, forest vegetation of any climatic and edaphic condition varies with the variation in environment of the habitat. As far as the Himalayan forest vegetation is concerned, it ranges from tropical dry deciduous forests in foothills to temperate forest in the high altitude. In the region, Oak and Pine are the dominated forest tree species, which provide fuel, fodder, and other basic needs to the villagers. Forest is one of the main sources of livelihood of people living in the region. Thus the Himalayan moist temperate forest is one the major forest type that characterized by extensive cover of trees belonging to conifers and broad leaved oak and other species in the forests which extends from 1500 to 3000 m elevation in Central Himalaya. Among the broad-leaved tree species, the three major oaks such as *Quercus leucotrichophora* A. Camus, *Quercus floribunda* Lindl. *Quercus semecarpifolia* Smith. and are found between 1600m and 2500m altitudes[1, 2]. According to Champion and Seth, oaks represent the climax vegetation which falls under sub-type 12/ C1a[3]. In forest, a large number of there are many other plant species but they vary from one forest to another forest and also changes significantly with in altitude and climate of the area. Thus species diversity is considered as a spatial form of textural diversity and treated both in structure and dynamics of the plant community[4]. The comparative analysis of species is based on species abundance models with associated diversity indices that provide valuable information of diversity in a forest community[5]. Status of biomass in the forests depicts the important ecological information especially in relation to dry matter storage and nutrients but every forest type has its own characteristics in the ecosystem. Biomass is a not only important from the standpoint of fundamental ecology but also relevant to planning for ecologically sustained development of the region[6]. Thus the estimation of biomass is prerequisite for determining the state and flux for understanding the dynamics of ecosystem[7, 8]. Most of the terrestrial carbon is stored in the tree trunk, branches, foliage and roots in the formed of the biomass in forest. Terrestrial vegetation and soil represent important sources and sinks of atmospheric carbon[9]. In nature, forest ecosystem act as a reservoir of carbon. They store huge quantities of carbon and regulate the carbon cycle by exchange of CO_2 from the atmosphere. Thus forest is one of the important carbon sinks of the terrestrial ecosystems. Plant uptakes the carbon dioxide by the process of photosynthesis and stores the carbon in the plant tissues. The forest play important role in the global carbon cycle by sequestering a substantial amount of carbon dioxide from the atmosphere. Carbon sequestration is a mechanism for the removal of carbon from the atmosphere by storing it in the biosphere. More photosynthesis means the more CO_2 is being converted into biomass, reducing carbon in the atmosphere and sequestering it in the plant tissues both in the aboveground and below ground[10]. The objectives of the study were to assess the tree density, diversity, biomass, productivity and carbon potential of forests in Nainital of Kumaun Himalaya.

MATERIALS AND METHODS

Description of study site

The present studied forest sites were located in Tippintop the surrounding area of Nainital in between 29⁰58' N lat. and 79⁰28' E long and 1500 and 2150m elevation. Tree analysis was carried out at three forest sites i.e. site-1, 2 and 3. The assessment of tree species was done by using quadrat of 10 x10m size. Total 30 quadrats were randomly placed in each forest to analyse the tree vegetation. In each quadrat, tree species were measured at 1.37m (diameter at breast height) with the help of meter tape from ground level. Tree density, abundance, basal area and IVI of trees were estimated in each forest [11]. Species diversity of vegetation in each studied forest was calculated by using Shannon-Weiner information index[12]. For the estimation of tree biomass, we used the allometric equation developed by Rawat and Singh for oak mixed forest[8]. The total biomass determine by summing up the respective component values of each tree species occurred in each site. The regression equation was used in the form y=a+b lnx, where y=dry weight of component (kg), x=GBH (cm), a=intercept, b= slope or regression coefficient and ln=log natural. The estimation of primary productivity, tree species was marked at breast height (1.37m) in each sample plot (the area 1 ha size) in each forest to assess diameter and height increment. The already of marked trees were re-measured for annual increment of diameter and height in each forest. The productivity of different tree components i.e. bole, branch, twig and leaf in aboveground part and stump root, lateral roots and fine roots in belowground part was assessed by using the regression equations. The net biomass accretion value (DB) for each component was estimated following the value of biomasses B_1 and B_2. Carbon stock and carbon sequestration values were estimated as suggested by Magnussen and Reed based on biomass, productivity and factor to get the carbon values of respective component[13]. The total carbon was estimated by summing up of carbon value of each tree component.

RESULTS

Tree composition

Total 8 tree species were present in forest site-1. The density of trees was 1010 ind.ha^{-1}. Of this, *Q. floribunda* (320 ind. ha^{-1}) followed by *Q. semecarpifolia* (250 ind.ha^{-1}), in forest site -1, total basal area was 63.93 m^2 ha^{-1}. Of this, maximum basal area accounted for *R. arboreum* (16.45) followed by *Q. floribunda* (16.32 m^2 ha^{-1}). Thus, the *Q. floribunda* is the most importance tree species in this forest community. The tree species diversity ranged from 0.112 to 0.525 in the studied forests (Table 1).

Total 4 tree species were present in forest site-2. The density of trees was 1100 ind.ha^{-1}. Of this, *Q. floribunda* (680 ind.ha^{-1}) followed by *Q. semecarpifolia* (320 ind.ha^{-1}) in forest site-2, total basal area was 31.81 m^{2}ha^{-1}. Of this, maximum basal area accounted for *Q. floribunda* (12.24 m^2 ha^{-1}) followed by *Q. semecarpifolia* (12.24 m^2 ha^{-1}). Thus the *Q. floribunda* is the most importance tree species in this forest community. The tree species diversity ranged from 0.177 to 0.518 in the studied forests (Table 1).

Total 4 tree species were present in forest site-3. The density of trees was 980 ind.ha^{-1}. Of this, *Q. leucotrichophora* (430 ind.ha^{-1}) followed by *Q. floribunda* (270 ind.ha^{-1}) in forest site-3, total basal area was 59.97 m^2 ha^{-1}. Of this, maximum basal area accounted for *Q. leucotrichophora* (35.69 m^2 ha^{-1}) followed by *Q. floribunda* (11.34 m^2 ha^{-1}). Thus the *Q. leucotrichophora* is the most importance tree species in this forest community. The tree species diversity ranged from 0.247 to 0.0521 in the studied forests (Table 1).

Biomass

The total forest biomass was 525.1 t ha^{-1} in forest site-1. Of this, *Q. floribunda* accounted for 44.2% followed by *Q. semecarpifolia* (25.6%) (Table 2). Of the total biomass, bole, branches, twigs, leaves, and roots account for 41.8, 23.2, 10.3, 10.3 and 14.3%, respectively (Table 2). Among the tree species, different components such as bole, branches, twigs, leaves and accounted for 34.9-65.7, 12.6-29.4, 4.6-11.9 and 3.1-17.1, respectively. The biomass of roots in different tree species shared 9.2-28.5, respectively (Table 2). The total forest biomass was 481.0 t ha^{-1} in forest site-2. Of this, *Q. floribunda* contributed 54.2% followed by *Q. semecarpifolia* (28.2%) (Table 2). Of the total biomass, bole, branches, twigs, leaves, and roots account for 38.8, 24.0, 11.0, 11.5 and 14.7%, respectively (Table 2). Among the tree species, different components such as bole, branches, twigs and leaves accounted for 32.9-50.9, 20.9-30.3, 8.8-11.7 and 2.5-16.9, respectively. The biomass of roots in different tree species shared 7.5-17.6, respectively (Table 2).Total forest tree biomass was 569.0 t ha^{-1} in the forest site-3. Of this, *Q. leucotrichophora* contributed (46.9%) followed by *Q. floribunda* (30.6%) (Table 2). Of the total biomass, bole, branches, twigs, leaves, and roots accounted for 43.3, 26.4, 10.5,

Table 1: Tree species analysis in Oak dominated forests in the surrounding area of Nainital in Kumaun Himalaya

Name of tree		Site-1			Site-2			Site-3	
species	D	BA	H '	D	BA	H '	D	BA	H '
Q. leucotrichophora	130	5.46	0.381	70	5.88	0.253	430	35.69	0.521
Q. floribunda	320	16.32	0.525	680	12.24	0.429	270	11.34	0.512
Q. semecarpifolia	250	14.0	0.499	320	10.24	0.518	220	8.8	0.484
R. arboreum	70	16.45	0.267	-	-	-	-	-	-
C. deodara	120	9.12	0.365	-	-	-	-	-	-
M. duthiei	20	0.26	0.112	30	3.45	0.177	-	-	-
L. umbrosa	30	0.78	0.151	-	-	-	-	-	-
M. esculenta	70	1.54	0.267	-	-	-	60	4.14	0.247
A. oblongum	-	-	-	-	-	-	-	-	-
Total	1010	63.93	2.57	1100	31.81	1.38	980	59.97	1.76

Note: D= Density, TBA=Total Basal Area, IVI=Important Value Index, H '=Species diversity

Table 2: Component -wise tree biomass (t ha^{-1}) in Oak dominated forests in the surrounding area of Nainital in Kumaun Himalaya

Name of Species	Bole	Branches	Twigs	Leaves	Roots*	Total
Forest site-1						
Quercus leucotrichophora	30.32	18.59	6.58	1.94	5.79	63.22
A. Camus	(48.0)	(29.4)	(10.4)	(3.1)	(9.2)	(12.1)
Quercus floribunda Lindl.	80.79	48.74	26.1	39.46	36.2	231.29
	(34.9)	(21.1)	(11.3)	(17.1)	(15.7)	(44.2)
Quercus semecarpifolia Smith.	58.82	36	14	8.18	16.79	133.79
	(44.0)	(26.9)	(10.5)	(6.1)	(12.5)	(25.6)
Rhododendron arboreum Smith.	4.21	2.78	1.06	0.47	3.4	11.92
	(35.3)	(23.3)	(8.9)	(3.9)	(28.5)	(2.3)
Cedrus deodara Loud.	29.5	5.67	2.06	1.43	6.25	44.91
	(65.7)	(12.6)	(4.6)	(3.2)	(13.9)	(8.6)
Machilus duthiei King.	2.36	1.53	0.7	0.41	0.88	5.88
	(40.1)	(26.0)	(11.9)	(7.0)	(15.0)	(1.1)
Litsea umbrosa Nees.	4.13	2.63	1.15	0.67	1.69	10.29
	(40.2)	(25.6)	(11.2)	(6.5)	(16.5)	(2.0)
Myrica esculenta Buch-	8.9	5.68	2.52	1.46	3.71	22.27
Ham. ex D. Don	(40.0)	(25.5)	(11.3)	(6.6)	(16.7)	(4.3)
Total	219.03	121.62	54.17	54.02	74.71	525.05
	(41.8)	(23.2)	(10.3)	(10.3)	(14.3)	(100)
Forest site-2						
Quercus leucotrichophora	29.90	17.76	5.15	1.49	4.40	58.69
A. Camus	(50.9)	(30.3)	(8.8)	(2.5)	(7.5)	(12.2)
Quercus floribunda Lindl.	85.68	54.55	30.53	44.07	45.90	260.74
	(32.9)	(20.9)	(11.7)	(16.9)	(17.6)	(54.2)
Quercus semecarpifolia Smith.	59.03	36.32	14.52	8.47	17.60	135.94
	(43.4)	(26.7)	(10.7)	(6.2)	(12.9)	(28.3)
Machilus duthiei King.	11.84	7.02	2.48	1.45	2.89	25.68
	(46.1)	(27.3)	(9.6)	(5.7)	(11.3)	(5.3)
	186.45	115.66	52.68	55.48	70.79	481.05
Total	(38.8)	(24.0)	(11.0)	(11.5)	(14.7)	(100)
Forest site-3						
Quercus leucotrichophora	130.77	79.34	26.18	7.65	22.75	266.69
A. Camus	(49.0)	(29.7)	(9.8)	(2.9)	(8.5)	(46.9)
Quercus floribunda Lindl.	60.57	36.62	19.67	29.66	27.53	174.05
	(34.8)	(21.0)	(11.3)	(17.0)	(15.8)	(30.6)
Quercus semecarpifolia Smith.	39.99	24.80	10.07	5.87	12.23	92.96
	(43.0)	(26.7)	(10.8)	(6.3)	(13.2)	(16.3)
Acer oblongum Wall.	15.14	9.29	3.61	2.11	5.14	35.29
	(42.9)	(26.3)	(10.2)	(6.0)	(14.6)	(6.2)
Total	246.48	150.04	59.53	45.30	67.65	568.99
	(43.3)	(26.4)	(10.5)	(8.0)	(11.9)	(100)

Note: * Roots component includes stump root (3.8 %), lateral roots (1.4-6.7 %) and fine roots (0.1-1.2%) in forest site-1 , stump root (3.2-14.8 %), lateral roots (1.3-4.0 %) and fine roots (0.1-0.3%) in forest site-2, stump root (4.6-23.4 %), lateral roots (0.5-12.1 %) and fine roots (0.04-1.1 %) forest site-3.

8.0 and 11.9 % respectively (Table 2). Among the tree species, different components such as bole, branches, twigs and leaves accounted for 34.8-49.0, 21.0-29.7, 9.8-113 and 2.9-17.0, respectively. The biomass of roots in different tree species shared 8.5-15.8, respectively (Table 2).

Primary productivity

Total primary productivity was 16.9 t $ha^{-1}yr^{-1}$ in forest site-1. Of this, *Q. floribunda* accounted for 7.7 t $ha^{-1}yr^{-1}$ followed by *Q. semecarpifolia* (3.4 t $ha^{-1}yr^{-1}$) (Table 3). Among the tree species, different components of trees, the primary productivity was in order: bole (45.7%)> branches (24.1%)> roots (including stump roots, lateral roots and fine roots) (11.4 %)>foliage (10.1 %)> twigs (9.2 %), respectively (Table 3). Total productivity was 20.9 t $ha^{-1}yr^{-1}$ in forest site-2**.** Of this, *Q. floribunda* accounted for 14.8 t $ha^{-1}yr^{-1}$ followed by *Q. semecarpifolia* (4.2 t $ha^{-1}yr^{-1}$) (Table 3). Among the different components of tree productivity was in order: bole (39.7%)> branches (32.2%)> foliage (13.6%)> roots (13.1%)> twigs (10.4%), respectively (Table 3). Total productivity was 19.1 t $ha^{-1}yr^{-1}$ in forest site-3. Of this, Q. *floribunda* accounted for 7.2 t $ha^{-1}yr^{-1}$ followed by *Q. leucotrichophora* (7.3 t $ha^{-1}yr^{-1}$) (Table 3). Among the different components of tree productivity was in order: bole (46%)> branches (26.5%)> roots (10.0%) >twigs (9.0%) >foliage (8.6%), respectively (Table 3).

Carbon stock

Total carbon stock of tree species was 249.1 t ha^{-1} in forest site-1. Of this, *Q. floribunda*

Table 3: Component-wise tree productivity (t ha^{-1} yr^{-1}) of Oak dominated forests site

Name of species	Bole	Branches	Twigs	Leaves	Roots*	Total
Forest site-1						
Q. leucotrichophora	1.16 (52.0)	0.69 (30.9)	0.18 (8.2)	0.05 (2.3)	0.15 (6.7)	2.24 (100)
Q. floribunda	2.93 (38.1)	1.64 (21.3)	0.80 (10.5)	1.33 (17.3)	0.98 (12.8)	7.69 (100)
Q. semecarpifolia	1.62 (47.9)	0.95 (28.2)	0.30 (8.9)	0.17 (5.1)	0.33 (9.9)	3.38 (100)
R. arboreum	0.08 (36.0)	0.05 (20.9)	0.01 (5.2)	0.002 (1.0)	0.08 (36.9)	0.22 (100)
C. deodar	0.85 (87.2)	0.10 (9.8)	0.02 (2.2)	0.01 (1.3)	0.09 (8.6)	1.07 (100)
M. duthiei	0.12 (45.6)	0.07 (27.2)	0.03 (9.8)	0.02 (5.8)	0.03 (11.5)	0.27 (100)
L. umbrosa	0.35 (45.7)	0.21 (27.1)	0.07 (9.5)	0.04 (5.6)	0.09 (12.2)	0.78 (100)
M. esculenta	0.57 (45.2)	0.34 (27.1)	0.12 (9.4)	0.07 (5.6)	0.16 (12.8)	1.27 (100)
Total	7.69 (45.7)	4.05 (24.1)	1.54 (9.2)	1.70 (10.1)	1.93 (11.4)	16.91 (100)
Forest site-2						
Q. leucotrichophora	0.71 (53.7)	0.41 (30.7)	0.10 (7.2)	0.03 (2.1)	0.08 (6.3)	1.33 (100)
Q. floribunda	5.37 (36.1)	3.15 (21.2)	1.66 (11.1)	2.55 (17.1)	2.16 (14.5)	14.88 (100)
Q. semecarpifolia	1.98 (47.1)	1.16 (27.6)	0.39 (9.2)	0.23 (5.6)	0.44 (10.6)	4.20 (100)
M. duthiei	0.22 (50.3)	0.13 (29.5)	0.03 (7.3)	0.02 (4.5)	0.04 (8.4)	0.43 (100)
Total	8.28 (39.7)	4.84 (23.2)	2.17 (10.4)	2.83 (13.6)	2.72 (13.1)	20.85 (100)
Forest site-3						
Q. leucotrichophora	3.74 (53.3)	2.18 (31.0)	0.52 (7.4)	0.15 (2.1)	0.43 (6.2)	7.03 (100)
Q. floribunda	2.68 (37.4)	1.53 (21.4)	0.77 (10.7)	1.23 (17.2)	0.96 (13.3)	7.16 (100)
Q. semecarpifolia	1.73 (47.9)	0.99 (27.5)	0.33 (9.0)	0.19 (5.3)	0.37 (10.2)	3.61 (100)
A. oblongum	0.62 (48.3)	0.35 (27.5)	0.11 (8.3)	0.06 (5.0)	0.14 (10.9)	1.28 (100)
Total	8.77 (46.0)	5.06 (26.5)	1.72 (9.0)	1.63 (8.6)	1.90 (9.9)	19.07 (100)

Note: * Roots component includes stump root (3-11.4%), lateral roots (1.2-9.3%) and fine roots (0.1-0.9%) in forest site-1, stump root (3.0-12.5%), lateral roots (1.0-2.9%) and fine roots (0.1-0.4%) in forest site-2, stump root (2.7-11.5%), lateral roots (1.1-3.2%) and fine roots (0.1-0.2%) forest site-3.

Table 4: Component-wise carbon stock (t ha^{-1}) in Oak dominated forests site

Name of Species	Bole	Branches	Twigs	Leaves	Roots*	Total
Forest site-1						
Quercus leucotrichophora A. Camus	14.40	8.83	3.12	0.92	2.75	30.02
	(48.0)	(29.4)	(10.4)	(3.1)	(9.2)	(12.0)
Quercus floribunda Lindl.	38.38	23.15	12.40	18.74	17.20	109.87
	(34.9)	(21.1)	(11.3)	(17.1)	(15.7)	(43.8)
Quercus semecarpifolia Smith.	27.94	17.10	6.65	3.89	7.98	63.56
	(44.0)	(26.9)	(10.5)	(6.1)	(12.5)	(25.3)
Rhododendron arboreum Smith.	2.00	1.32	0.51	0.22	1.62	5.67
	(35.3)	(23.3)	(8.9)	(3.9)	(28.6)	(2.3)
Cedrus deodara Loud.	14.34	2.80	1.05	0.73	3.13	22.05
	(65.0)	(12.7)	(4.7)	(3.3)	(14.2)	(8.8)
Machilus duthiei King.	1.12	0.73	0.33	0.19	0.42	2.79
	(40.2)	(26.1)	(11.9)	(6.9)	(15.1)	(1.1)
Litsea umbrosa Nees.	1.96	1.25	0.55	0.32	0.81	4.89
	(40.1)	(25.5)	(11.2)	(6.5)	(16.6)	(1.9)
Myrica esculenta Buch- Ham. ex D. Don	4.23	2.70	1.20	0.69	1.77	10.59
	(39.9)	(25.5)	(11.3)	(6.6)	(16.7)	(4.9)
Total	104.37	57.88	25.81	25.70	35.68	251.01
	(41.8)	(23.2)	(10.3)	(10.3)	(14.3)	(100)
Forest site-2						
Quercus leucotrichophora A. Camus	14.20	8.43	2.45	0.71	2.09	27.88
	(50.9)	(30.2)	(8.8)	(2.5)	(7.5)	(12.2)
Quercus floribunda Lindl.	40.70	25.91	14.50	20.93	21.81	123.85
	(32.9)	(20.9)	(11.7)	(16.9)	(17.6)	(54.2)
Quercus semecarpifolia Smith.	28.04	17.25	6.90	4.02	8.36	64.57
	(43.4)	(26.7)	(10.7)	(6.2)	(12.9)	(28.3)
Machilus duthiei King.	5.62	3.34	1.18	0.69	1.37	12.20
	(46.1)	(27.3)	(9.6)	(5.7)	(11.3)	(5.3)
Total	88.56	54.93	25.03	26.35	33.63	228.50
	(38.8)	(24.0)	(11.0)	(11.5)	(14.7)	(100)
Forest site-3						
Quercus leucotrichophora A. Camus	62.11	37.69	12.44	3.63	10.81	126.68
	(49.0)	(29.7)	(9.8)	(2.9)	(8.5)	(46.9)
Quercus floribunda Lindl.	28.77	17.39	9.34	14.09	13.09	82.68
	(34.8)	(21.0)	(11.3)	(17.0)	(15.8)	(30.6)
Quercus semecarpifolia Smith.	19.00	11.78	4.78	2.79	5.80	44.15
	(43.0)	(26.7)	(10.8)	(6.3)	(13.1)	(16.3)
Acer oblongum Wall.	7.19	4.41	1.71	1.00	2.45	16.76
	(42.9)	(26.3)	(10.2)	(6.0)	(14.5)	(6.2)
Total	117.07	71.27	28.27	21.51	32.15	270.27
	(43.3)	(26.4)	(10.5)	(8.0)	(11.9)	(100)

Note: * Roots component includes stump root (3.8-20.6 %), lateral roots (1.3-6.7 %) and fine roots (0.1-1.2%) in forest site-1, stump root (3.2-14.8 %), lateral roots (1.3-3.9 %) and fine roots (0.1-0.3 %) in forest site-2, stump root (3.6-13.4 %), lateral roots (1.5-4.5 %) and fine roots (0.1-0.4 %) forest site-3.

contributed 44% followed by *Q. semecarpifolia* (25.5%) (Table 4). Of the total carbon stock, bole, branches, twigs, leaves, and roots account for 41.8, 23.2, 10.3, 10.3 and 14.3%, respectively (Table 4). Among the tree species, different components such as bole, branches, twigs, leaves accounted for 35.3-65.0, 12.7-29.0, 4.7-11.9 and 3.1-17.7%, respectively. The carbon stock of roots in different tree species shared 9.2-28.6, respectively (Table 4). Total tree carbon stock was 228 t ha^{-1} in forest site-2. Of this, *Q. floribunda* contributed 54.2% followed by *Q. semecarpifolia* (28.3%). The component- wise carbon stock of different tree species is given in (Table 4). Of the total carbon stock, bole, branches, twigs, leaves and roots accounted for 38.8, 24.0, 11.0, 11.5 and 14.7%, respectively (Table 4). Among the tree species, different components such as bole, branches, twigs and leaves accounted for 32.9-50.9, 20.9-30.2, 8.8-11.7 and 2.5-16.6, respectively. The carbon stock of roots in different tree species shared 7.5-17.6, respectively (Table 4). Total carbon stock of tree species was 270 t ha^{-1} in forest site-3. Of this, *Q. leucotrichophora* contributed 46.9% followed by *Q. floribunda* (30.6%) is given in (Table 4). Of the total carbon stock, bole, branches, twigs, leaves and roots accounted for 43.3, 26.4, 10.5, 8.0 and 11.9%, respectively (Table 4). Among the tree species, different components such as bole, branches, twigs and leaves accounted for 34.8-49.0, 21.0-29.7, 9.8-113 and 2.9-17.0, respectively. The carbon stock of roots in different tree species shared 8.5-15.8, respectively (Table 4).

Carbon sequestration

Total carbon sequestration potential of tree species was 7.99 t $ha^{-1}yr^{-1}$ in forest site-1. Of this,

Table 5: Component wise tree carbon sequestration ($tha^{-1}yr^{-1}$) of Oak dominated forests

Name of Species	Bole	Branches	Twigs	Leaves	Roots*	Total
Forest site-1						
Q. leucotrichophora	0.55 (52.0)	0.33 (30.9)	0.09 (8.2)	0.02 (2.3)	0.07 (6.7)	1.06 (100)
Q. floribunda	1.39 (38.1)	0.78 (21.3)	0.38 (10.5)	0.63 (17.3)	0.47 (12.8)	3.65 (100)
Q. semecar pifolia	0.77 (47.9)	0.45 (28.1)	0.14 (8.8)	0.08 (5.1)	0.16 (10.1)	1.61 (100)
R. arboreum	0.04 (36.0)	0.02 (20.9)	0.01 (5.2)	0.001 (1.0)	0.04 (36.9)	0.11 (100)
C. deodara	0.36 (77.4)	0.05 (9.7)	0.01 (2.2)	0.01 (1.3)	0.04 (9.4)	0.46 (100)
M. duthiei	0.06 (45.6)	0.04 (27.2)	0.01 (9.8)	0.01 (5.8)	0.01 (11.5)	0.13 (100)
L. umbrosa	0.17 (45.7)	0.10 (27.0)	0.03 (9.5)	0.02 (5.6)	0.05 (12.3)	0.37 (100)
M. esculenta	0.27 (45.2)	0.16 (27.1)	0.06 (9.4)	0.03 (5.6)	0.08 (12.8)	0.60 (100)
Total	3.61 (45.2)	1.92 (24.1)	0.73 (9.1)	0.81 (10.1)	0.92 (11.5)	7.99 (100)
Forest site-2						
Q. leucotricho phora	0.34 (53.8)	0.20 (31.0)	0.04 (7.1)	0.01 (2.1)	0.04 (6.1)	0.63 (100)
Q. floribunda	2.55 (36.1)	1.50 (21.2)	0.79 (11.1)	1.21 (17.1)	1.03 (14.5)	7.07 (100)
Q. semecarpifolia	0.94 (47.1)	0.55 (27.6)	0.18 (9.2)	0.11 (5.6)	0.21 (10.6)	2.00 (100)
M. duthiei	0.13 (49.8)	0.08 (29.1)	0.02 (7.7)	0.01 (4.7)	0.02 (8.7)	0.26 (100)
Total	3.96 (39.8)	2.32 (23.3)	1.04 (10.4)	1.35 (13.5)	1.30 (13.0)	9.96 (100)
Forest site-3						
Q. leucotricho phora	1.78 (53.3)	1.03 (31.0)	0.25 (7.4)	0.07 (2.1)	0.21 (6.2)	3.34 (100)
Q. floribunda	1.27 (37.4)	0.73 (21.4)	0.36 (10.7)	0.58 (17.2)	0.45 (13.3)	3.40 (100)
Q. semecarpifolia	0.82 (47.9)	0.47 (27.5)	0.15 (9.0)	0.09 (5.3)	0.17 (10.2)	1.71 (100)
A. oblongum	0.29 (48.3)	0.17 (27.5)	0.05 (8.3)	0.03 (5.0)	0.07 (10.9)	0.61 (100)
Total	4.16 (46.0)	2.40 (26.5)	0.82 (9.0)	0.78 (8.6)	0.90 (9.9)	9.06 (100)

Note: * Roots component includes stump root (3-26.7%), lateral roots (1.2-9.3%) and fine roots (0.1-0.9%) in forest site-1, stump root (2.7-12.5%), lateral roots (1.0-3.2%) and fine roots (0.1-0.2%) in forest site-2, stump root (2.7-11.5%), lateral roots (1.1-3.2%) and fine roots (0.1-0.2%) forest site-3.

Q. floribunda accounted for 3.65 t ha^{-1}yr^{-1} followed by *Q. semecarpifolia* 1.61 t ha^{-1}yr^{-1}. Among the different components of tree carbon sequestration was in order: bole (45.2%)> branches (24.1%)> roots (11.5%)> foliage (10.1%)> twigs (9.1%) (Table 5). Total carbon sequestration potential of tree species was 9.96 t ha^{-1}yr^{-1} in forest site-2. Of this, *Q. floribunda* accounted for 7.07 t ha^{-1}yr^{-1} followed by *Q. semecarpifolia* 2.0 t ha^{-1}yr^{-1}. Among the different components of tree carbon sequestration was in order: bole (39.8%)> branches (23.3%)> foliage (13.5%)> roots (13.0%)> twigs (10.1%) (Table 5). Total carbon sequestration potential of tree species was 9.06 t ha^{-1}yr^{-1} in forest site-3. Of this, *Q. floribunda* accounted for 3.40 t ha^{-1}yr^{-1} followed by *Q. leucotrichophora* 3.34 t ha^{-1}yr^{-1}. Among the different components of tree carbon sequestration was in order: bole (46.0 %)> branches (26.5%)> stump roots (9.9%)>twigs (9.0%) > foliage (8.6%) (Table 5).

DISCUSSION

Forest is one of the major natural resources of Himalaya. They play vital role in the development of the region. This study was carried out to assess the biomass, productivity and carbon sequestration potential of oak dominated broad-leaved forests of Nainital in Kumaun Himalaya. The Kumaun region accounted for 40.3 % forest cover, which fulfils the basic needs of fuel, fodder and small timber of the villagers obtained either from community forests (van panchayats) and or government managed forests. In the recent days, variation of climate has impacted the biodiversity, , growth and productivity of forests, therefore, the assessment of forests for productivity and carbon potential is very essential for current and future conservation and sustainable forest development point of view. The tree density 980-1100 ind ha^{-1}. Of this, present values fall within range 420-1640 ind.ha^{-1} reported for temperate forests of western Himalaya[14] and 920-1345 ind.ha^{-1} for natural forests of Kumaun Himalaya[15] and 550-1250 ind.ha^{-1} in oak dominated forests in Kumaun Himalaya[16], 960-1170 ind.ha^{-1} in Van Panchayat forest in Kumaun Himalaya[17] and 1040-1260 ind.ha^{-1} for pine forests in Kumaun Himalaya[18] but on higher side than 570-760 ind.ha^{-1} reported for oak forest[8]. However, basal area (31.81-63.93 m^2 ha^{-1}) of oak dominated forests was lower side than 58.7-93.0 m^2 ha^{-1} reported for natural forests in Kumaun Himalaya[14]. Present estimates of basal area (31.81-63.93 m^2 ha^{-1}) are higher than 33.9-36.8 m^2 ha^{-1} reported for oak forests[6] and 36.3-56.4 m^2 ha^{-1} for pine forests in Kumaun Himalaya[18]. Tree species diversity ranged between 1.38-2.57 in Oak dominated forests, which falls within the range 1.31 to 2.69 of oak dominated forests in Kumaun Himalaya[16] and higher than 1.01 to 1.65 of oak mixed forests[17].

Present biomass estimates (481-569 t ha^{-1}) are higher (fig.1) than 285-458 t ha^{-1} reported for oak forests[8], 236-400 t ha^{-1} for Oak dominated forests of high altitude[19] but lower than 651-718 t ha^{-1} of natural

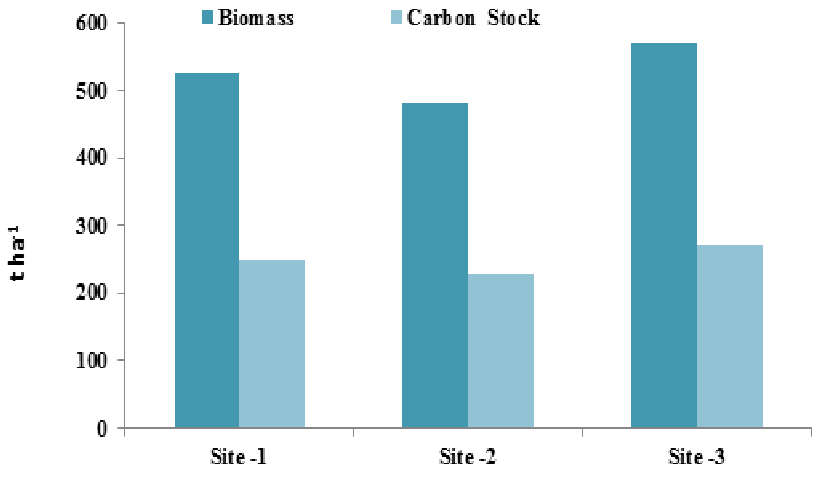

Fig. 1: Bar diagram is showing biomass and carbon stock of oak dominated forests in each forest site

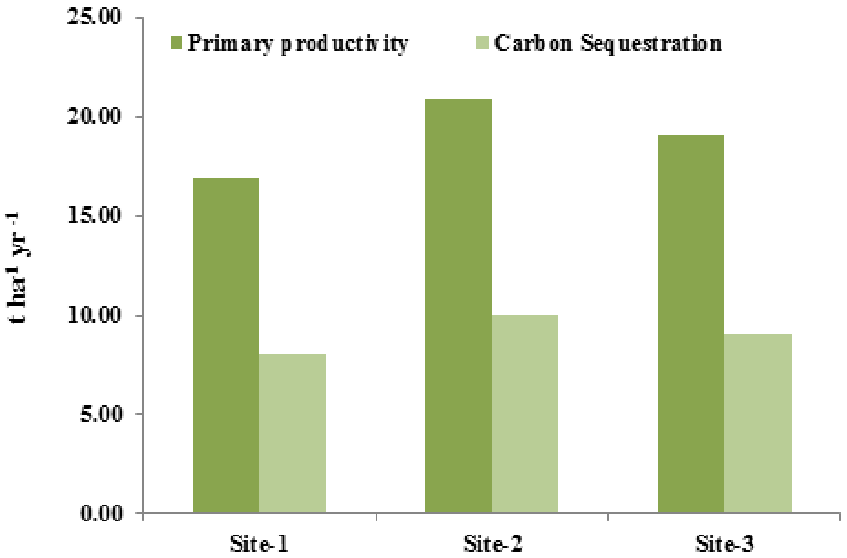

Fig. 2: Bar diagram is showing primary productivity, and carbon sequestration potential of oak dominated forests in each forest site

Table 6: Comparative study of different parameter of Oak dominated forests in India

Forest types	Density (ind.ha^{-1})	TBA (m^2 ha^{-1})	H'	Biomass (t ha^{-1})	Productivity (t ha^{-1} yr^{-1})	CS (t ha^{-1})	CSP (t ha^{-1} yr^{-1})	References
Oak forest	570-760	33.9-36.8	-	285.3-458.5	13.2-16.6	-	-	Rawat and Singh, 19888
Oak forest	920-1345	58. 7-93	-	651-718	-	309-341	-	Lodhiyal et al., 201415
Oak forest	1330	36.77	-	101.45	-	59.4	-	Lodhiyal and Lodhiyal, 201222
Mixed oak forest	-	-	-	426-782	15.9-25.1	-	-	Rana et al., 198920
Kharsu ok forest	-	-	-	590	24.6	-	-	Adhikari et al., 199519
Oak non-degraded forest	-	-	-	-	-	242.6-290.6	5.5-6.2	Jeena et al., 2008 21
Oak degraded forest	-	-	-	-	-	16.7-18.5	1.5-1.8	Jeena et al., 200821
Oak dominated forest	550-1250	33.9-62.6	1.31-2.69	-	-	-	-	Singh et al., 2014 16
Oak mixed forest	960-1170	-	1.01-1.65	-	-	-	-	Pandey and Lodhiyal, 201517
Tilonj oak forest dominated forests	300-1190	-	0.421-1.769	-	-	-	-	Lodhiyal et al., 201523
Oak dominated forests	980-1010	31.81-63.93	0.29-0.77	481-569	16.9-20.9	228.5-270.3	7.99-9.96	Present study

forests in Kumaun Himalaya[15] and 154-301 t ha^{-1} in pine forests in Kumaun Himalaya[18] and 590 t ha^{-1} of Kharsu oak forests in higher altitude[19] and 426-782 t ha^{-1} in oak forest site in Kumaun Himalaya[20]. The carbon stock was 229-270 t ha^{-1} (Fig.1), which falls within the range 229.341 t ha^{-1} of natural forests of Kumaun in central Himalaya[15] and 243-290 t ha^{-1} of oak and pine forests in non-degraded forest sites in Kumaun Himalaya[21]. But present values are on higher side than 59.41 t ha^{-1} oak and pine mixed forest of Lohaghat in Kumaun Himalaya[22] and 16.73-18.54 t ha^{-1} of oak and pine forests in degraded forests [21].

The primary productivity values (17.0 to 21.0 t ha^{-1} yr^{-1}) are higher (Fig.2) than 13.2-16.6 t $ha^{-1}yr^{-1}$ of oak forests[8] and 7.58-18.70 t $ha^{-1}yr^{-1}$ of Chir-pine forests in central Himalaya[7] and lower side than 24.6 t ha^{-1} yr^{-1} of Kharsu oak forest in higher altitude[19] (Fig.2). The carbon sequestration was 8.0-10.0 t ha^{-1} yr^{-1} in the studied forests. However, the estimates of carbon sequestration are higher than 5.48-6.23 t ha^{-1} yr^{-1} non- degraded oak forests and 1.47-1.84 t ha^{-1} yr^{-1} in degraded oak forests[21] (Fig.2). Detail comparative accounts of different oak forests on the aspects of biomass, productivity, and carbon stock and carbon sequestration is given in Table 6.

Present findings of oak dominated forests are on higher side than earlier results of forests studied in the region, therefore, it is concluded that the studied forests were not affected much from nearby humans pressure and variation in climate. This is because of mainly two reasons: (i) these forests were judiciously cared and managed by foresters by using better conservation practices as well as implementation of strict rules and regulations and also (ii) adequate support and timely co-operation of community people residing in nearby areas.

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