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Temporal variation in tree biomass and carbon stocks of *Pinus roxburghii* Sargent forests of Rajouri forest division in Jammu & Kashmir State

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Abstract

The present study was conducted on *Pinus roxburghii* (chir) forests of Rajouri Forest Division in Jammu & Kashmir State to assess the temporal variations of carbon biomass and C storage between 1995-96 and 2015-16. Results of present study unveil that despite an increase of Chir tree density from 132.60 trees/ha during 1995-96 assessment to 197.61 trees/ha during 2015-16, the growing stock as well as aboveground tree biomass of Chir forests, which were 16.28 lac m^3 and 9.73 lac tonnes in 1995-96, declined to 12.10 lac m^3 and 7.24 lac tonnes, respectively by 2015-16. Similarly, the total C stocks of Chir forests (aboveground + belowground), which stood at 5.90 lac tonnes during 1995-96, declined to 4.39 lac tonnes; a decrease of 25.59% in assessment period. In line with these changes, the C density of these forests also witnessed a decline from 58.95 Mg ha^{-1} to 43.84 Mg ha^{-1}. Such declining trends definitely indicate forest degradation; poor forest health, cumulatively attributed to excessive removals, skewed distribution of Chir trees, subdued movement of trees from lower to higher diameter classes and increased anthropogenic pressure on forests in the division.

Key words: ***Biomass, C density, Carbon sequestration, Carbon stocks, Chir trees, Pine forests, Stem density***

Introduction

The role of forest ecosystems in global carbon cycle needs no reiteration or over-emphasis as forests can be both source as well as sink of carbon, depending on the specific management regime and activities (IPCC, 2000). Globally, forests cover an area of 3999 million ha, contain 531 billion m^3 of growing stocks (FAO, 2015) and store more than 362.6 Pg C(Peta gram carbon) with live biomass C density of 94.1Mg (mega gram) C ha^{-1} (Pan *et al*., 2011, 2013). This is much higher than any other terrestrial system and thus forests act as a mitigating factor towards climate change. The annual CO_2 exchange between forests and atmosphere through photosynthesis and respiration are estimated to be approximately 50 Pg y^{-1} and gross primary production flux of 123 ± 8 Pg of C year $^{-1}$ (Beer *et al.*, 2010). With an offset potential of 30% of global CO_2 emissions from fossil fuel combustion and mitigation opportunities estimated to be 4.00 to 6.2 Pg yr $^{-1}$, the established forests act as a major sink of carbon from the atmosphere (Ussiri and Lal, 2017). However, through processes of forest removals, degradation, decomposition, respiration etc., forests simultaneously act as source of carbon hence, constitute critical component of the global carbon cycle. Under extreme conditions, the impacts of climate change are likely to be catastrophic to human survival and may lead to irreversible loss of natural ecosystems. Because of this, forests do play a vital role in global climate change mitigation (Miller *et al.,* 2007). However, due to enhanced anthropogenic interventions, the annual global loss of forest area and forest degradation has become the major source of CO_2 emissions from land-use, land-use changes (FAO, 2016). Against 7.3M ha^{-1} in the 1990's, an average of 4.6 M ha^{-1} of forests were cleared and converted for production of commodities during past 25 years, resulting in decline of average forest growing stock from less than 60 m^3 ha^{-1} in Eastern, Southern Africa and North Africa to more than 200 m^3 ha^{-1} in Oceania in 2015 (Keenan *et al.,* 2015). Carbon stored in forest ecosystems over the long term get released rapidly and in considerable amounts to the atmosphere following such disturbances (Page *et al*., 2002). Correspondingly, the global forest C stocks have shown a decline of 13.6 Pg C between 1990 and 2015; most of it in living biomass. Forests being a biological entity are always in

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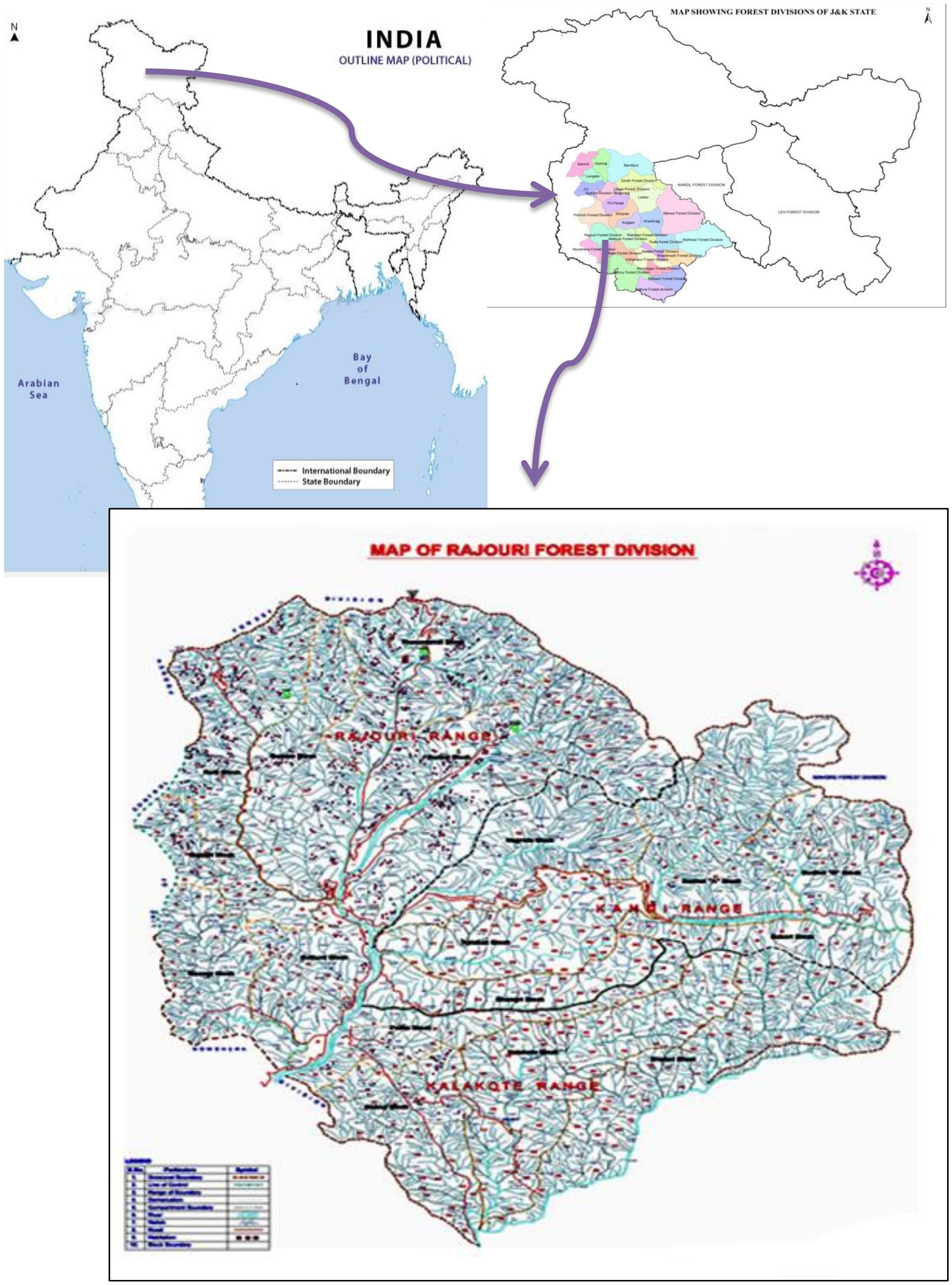
dynamic state of their geographical extent, structure, species composition, species migration and annual growth. The recent changes witnessed in forests due to impact of degradation and climate change have been well documented across the continents, which reflect a close bearing on forest biomass & C storage potential. India is no exception to phenomenon of degradation of forests and excessive removals for multiple reasons. Thus, knowledge of C stocks stored in different layers of forests become an important tool to assess the contribution of forest lands towards C cycle, shift in forest C storage potential and its allocations in different strata / layers to predict responses of forests towards future climatic changes. However, most of studies conducted on forest C sequestration reflect contributions of forests as C sinks in the global C cycle, yet great deal of uncertainty remains regarding the C sink of forests with respect to magnitude and location due to the incomplete knowledge of spatial and temporal dynamics of forest C storage. Hence, an accurate measurement of Carbon stocks and its temporal dynamics in forests become an important scientific basis to monitor carbon storage and emissions from these ecosystems under the National Greenhouse Gas Inventory mechanism of Inter- governmental Panel on Climate Change (IPCC, 2006a).Carbon storage and sequestration potential of different forests have been studied by various workers at global (Prentice and Fung., 1990; Smith *et al.,* 1993; Olson and Watson., 1982 ; Dixon *et al*., 1994; Pan *et al.*, 2011 ; Huang *et al.,* 2015 ; FAO, 2015; Calle *et al.*, 2016; Ngo *et al.*, 2013) and national level (Ravindranath *et al.*, 1997; Haripriya, 2003 ; Kishwan *et al* ., 2005 ; Manhas *et al.,* 2006 ; Kaul *et al*., 2011; Reddy *et al*., 2016), yet limited work on temporal changes in tree biomass and C storage of a particular forest is presently available in India. Using the past forest inventory data with recent assessments, some efforts were made (Chhabra *et al*., 2002; Sheikh *et al*., 2011) to work out the variations of forest biomass and C stocks of particular forests. But for few static studies with limited scope (Bhat *et al*., 2011 ; Dar and Sundarapandian, 2013), almost negligible work has been reported from the state of Jammu & Kashmir in general and Chir pine forests in particular. However, Shah *et al*., (2014) has assessed the temporal variation of tree biomass and C stocks of *Pinus roxburghii* forests over an area of 435 ha of Solan and Dharampur forest range of Solan Forest Division in Himachal Pradesh. *Pinus roxburghii* (Chir pine) forests, a native of inter-ranges of the Himalayan mountain system spanning from Afghanistan in west to Bhutan in east, extend over an estimated area of 8.90lac ha. Primarily, these forests are located at an elevation ranging between 450 to 2300 m a.s.l. and constitute one of the principle forest types of lower Himalayan Range; mostly in pure forests in its natural habitat but also occurs mixed with other conifers and broad leaved species as well. In the State of Jammu & Kashmir, *Pinus roxburghii* (Chir) forests cover an area of 1.92lac ha confined to Jammu province of the State (Annonymous, 2013) and constitute one among the fast growing conifer species. The present study on temporal variation of tree biomass and C stocks of *Pinus roxburghii* (Chir) forests was conducted on much larger canvas covering an expanse of 10013 ha in Rajouri Forest Division of Jammu & Kashmir State to assess the tree biomass, C Stocks(above + below ground) and C density using the forest inventory method. The broader objective of present study was to unveil the temporal variations registered between the assessment periods, underline the quantum of changes witnessed in extent, density and composition of chir forests over a specific period of time and various factors attributed to such changes so as to improve the understanding of C fluxes dynamics of these forests.

Material and Methods

Study Area

Present study has been carried out in Rajouri Forest Division (74^0 11' 03.03" E and 74^0 40' 21.95" E & 33^0 8' 47.77" to 30^0 35' 05.16" N, altitudinal range from 529 to 4660 m a.s.l.), having forest area of 72069 ha, with mild undulating hills at lower levels to high and very steep slopes culminating at Pir Panchal Range of Himalayan Mountains. The division experience dry hot summer conditions in lower plain areas between March and June while elevations above 1800 m receive significant snowfall during months of November to January. The mean maximum and mean minimum temperature of 29.6 °C and 9.2^0 C were recorded at Rajouri during May and January, respectively. The

Fig.1. Map showing Rajouri forest division in State of Jammu & Kashmir



mean annual precipitation of 804 mm is received in the division; two-third which is in form of monsoon rains during July to September and remaining as snowfall from January to March (https://www.worldweatheronline.com). Besides sizeable area under alpine pastures, scrub vegetation and natural blanks, forests of the division comprise of 14120 ha of *Pinus roxburghii* (Chir), 9037 ha of *Abies pindrow* (Fir) , 144 ha of *Pinus wallichiana* (Kail) and 9563 ha of mix broad leave. The temporal variations of tree biomass and C stocks of *Pinus roxburghii* Sargent (chir pine) forests has been carried out in all three ranges i.e. Rajouri, Kandi and Kalakote Range of Rajouri Forest Division.(Fig. 1).

Data collection and analysis

To estimate the existing Chir biomass and C stocks, Bitterlich's Random Sampling technique was adopted for laying a total of 231 sample points of 0.1 ha size each in 107 forest compartments (53 in Rajouri Range, 14 in Kandi Range and 40 in Kalakote Range) having predominantly Chir forests. A total of 10013 ha (out of 14120 ha Chir forests) was assessed during the present study whose area has remained constant during the last and present inventory cycle, thereby leaving the rocky outcrop, un-commercial & chir forests located close to Indo-Pak border. Each sample point laid on GT sheet was delineated on ground using Garmin e-trex Vista Model GPS to locate its exact geo-coordinates. Total enumeration of all tree individuals $\geq$10 cms dbh (diameter at breast height viz. 1.37m) lying inside the sample plot was conducted specifying name of forest, number & area of forest compartment, species-wise number of trees found in each diameter etc. The tree height was measured using "Ravi" digital altimeter. To have a comparative accuracy analysis of sample stocks vis-à-vis the total enumeration, wedge prism of known BAF (Basal area factor) was also used to measure the basal area of trees found in 360^0 sweep from the central point of sample plot. To assess the temporal variation in tree biomass and C storage potential of above specified chir forests, the inventory data of previous exercise conducted during the year 1995-96 have been used. Chir growing stock in each diameter class has been calculated by using the regression equation of $\sqrt{V} = 0.05131 + 3.9859D - 1.0245\sqrt{D}$ developed by of FSI Dehradun for *Pinus roxburghii* of Western Himalayas was used ; where V is volume, D is diameter of tree at breast height(dbh).

For estimating the biomass content of *Pinus roxburghii* (chir) forests, wood density of 0.46 was adopted as suggested by Uniyal *et al*., (2002) for J&K State. The Above Ground Biomass Density (AGBD) of tree components (stem, branches, twigs and leaves), was calculated using the default value of 1.3 of Biomass Expansion Factor (BEF) suggested by Brown (1997). The below ground biomass of the trees was calculated by the ratio of below-ground biomass to above-ground biomass as suggested by Mokany *et al*., (2006) and Singh *et al*.,(1994) in IPCC (2006b) Guidelines for National Greenhouse Gas Inventories. The AGBD and BGBD were added to get the Total Biomass Density (TBD). The C storage was estimated using the value of C fraction of aboveground forest biomass estimation factor of 0.47 suggested by IPCC (2006b). The Total Carbon Density (TCD) was computed by using the following formula:

$$Carbon\ (C\ Mg\ /ha) = Biomass\ (Mg/ha) \times Carbon(C)\ \%$$

where C=0.47

Results and Discussion

Based on present studies, the quantum of temporal variation in C stocks in Rajouri Forest Division between 1995-96 and 2015-16 is shown in Table-1.The diameter class–wise distribution of trees, growing stock, biomass and C stocks during 1995-96 and 2015-16 is given in Table- 2 while Table-3 depicts the intra-range variability in distribution of trees, growing stock, biomass and above & below ground C stocks of 1995-96 and 2015-16 assessment.

Aboveground Growing stocks

A comparison of two cycles of stock inventory show that the *Pinus roxburghii* (Chir) forests apparently witnessed significant changes in density and composition during last 20 years in the division thus, affecting its growing stocks, biomass and C storage potential (Table 1). Though chir tree number increased from 1330174 (132.60 trees/ha) assessed in 1995-96 to estimated 1978756 trees (Avg. 197.61 trees/ha) by 2015-16, yet the quantum of growing stocks, biomass and C storage registered a significant decline (Table 2). In the present study, the chir trees showed a skewed

Table – 1: Temporal variation of C stocks in Rajouri Forest Division between 1995-96 and 2015-16

Component	Range	Area (ha)	C stocks 1995-96	C stocks 2015-16	C t ha^{-1} 1995-96	C t ha^{-1} 2015-16	Difference C in tonnes
Tree aboveground	Rajouri	4816	208674.98	163770.63	43.42	34.00	-44904.35
	Kalakote	4344	298594.24	147579.37	48.01	33.97	-151014.9
	Kandi	853	40355.01	28993.36	47.30	33.99	-11361.65
	Total	**10013**	**457624.23**	**340343.36**	**45.70**	**33.99**	**-117280.9**
Tree below ground	Rajouri	4816	60515.74	47493.48	12.56	9.86	-13022.26
	Kalakote	4344	60492.33	42798.01	13.92	9.85	-17694.32
	Kandi	853	11702.95	8408.07	13.71	9.85	-3294.88
	Total	**10013**	**132711.02**	**98699.56**	**13.25**	**9.85**	**-34011.46**
Total	Rajouri	4816	269190.73	211264.11	55.89	43.86	-57926.62
	Kalakote	4344	269086.57	190377.39	61.94	43.82	-78709.18
	Kandi	853	52057.96	37401.43	61.02	43.84	-14656.53
	Total	**10013**	**590335.25**	**439042.93**	**58.95**	**43.84**	**-151292.3**

Table – 2 : Diameter class –wise distribution of trees, growing stock, biomass and C stocks during 1995-96 and 2015-16

Dia class (in cms)	No of Chir trees		Growing Stock (in m^3)		Tree Biomass (in tonnes)		C stocks (ABG+BG) (in tonnes)		Difference in C stocks (tonnes)
	1995-96	**2015-16**	**1995-96**	**2015-16**	**1995-96**	**2015-16**	**1995-96**	**2015-16**	
0-10	0	0	0	0	0	0	0	0	0
10-20	202521	622053	12151.26	37323.18	7266.45348	22319.26164	4405.650745	13532.16833	+9126.5176
20-30	249493	701466	72352.97	203425.14	43267.07606	121648.2337	26232.82822	73755.3241	+47522.496
30-40	272330	275640	193354.3	195704.4	115625.8714	117031.2312	70103.96583	70956.03548	+852.06965
40-50	265265	218282	355455.1	292497.88	212562.1498	174913.7322	128876.4314	106050.1959	**-22826.2355**
50-60	188353	94829	414376.6	208623.8	247797.2068	124757.0324	150239.4465	75640.18874	**-74599.2578**
60-70	107807	40123	355763.1	132405.9	212746.3338	79178.7282	128988.1022	48006.06291	**-80982.0393**
70-80	36141	19338	167694.24	89728.32	100281.1555	53657.53536	60800.46459	32532.56369	**-28267.9009**
80-90	5741	4018	35709.02	24991.96	21353.99396	14945.19208	12946.92654	9061.269958	**-3885.65658**
90-100	2039	2059	16434.34	16595.54	9827.73532	9924.13292	5958.555925	6017.001789	+58.445864
100-110	484	948	4917.44	9631.68	2940.62912	5759.74464	1782.903435	3492.133175	+1709.2297
110-120	0	0	0	0	0	0	0	0	0
Total	1330174	1978756	1628208.37	1210927.8	973668.60	724134.8244	590335.2754	439042.944	-151292.331

distribution pattern contrary to a normal chir forest (Figure 2) suggested by ICFRE, Dehradun (*www.frienvis.nic.in*)

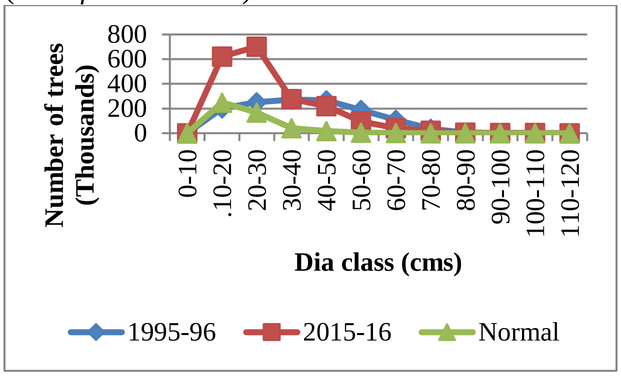


Fig. 2 : Normal and recorded diameter wise distribution of chir trees in different

The chir trees estimated during the present study show an increase of 648582 trees in division during the last two decades; which should supposedly enhance the aboveground biomass, C stocks and C density of these forests in a substantial manner. But contrary to this increase in tree number, the growing stocks of Chir forests have registered a decline from 16.28 lac m^3 inventoried during 1995-96 to 12.10 lac m^3 during 2015-16 assessment cycle (25.67% decline in growing stocks) in specified 107 forest compartments of the division. Similarly, the tree biomass, which stood at 9.73 lac tonnes during 1995-96 also witness a sharp decline to 7.24 lac tonnes during 2015-16 assessment (Table 2).

Though *Pinus roxburghii* is relatively a fast growing conifer with reasonably good annual increment, yet the temporal distributions of its aboveground carbon stocks in this division witnessed a declining trend during last two decades. Further, against the 50-60 cms diameter in 1995, the highest growing stocks and biomass Carbon was found to be stored in 40-50cm diameter class trees during the assessment conducted in 2015-16, reflecting a critical shift towards lower diameter tree classes for an apparent excessive removal of high diameter trees coupled with lower movement of chir trees from 40-50 cms to the higher diameter classes (Table 2, Fig. 2).

Aboveground biomass, Carbon stocks and C density:

With an average C density of 43.84 t ha^{-1} (against 58.95 t ha $^{-1}$ during 1995-96), a total of 439042.93 tonnes of C storage was estimated to be present in tree biomass of Chir forests in Rajouri division during 2015-16 (against 590335.25 tonnes assessed in 1995-96); 77.51 % of which is stored in aboveground tree biomass. Further, despite addition of 6.48 lac new Chir trees, the overall C storage in aboveground biomass, which stood at 457624. 23 tonnes during 1995-96, declined to 340343.36 tonnes in 2015-16; a decline of 11.71 t ha^{-1}. Such decrease in C density was observed in chir forests of all three ranges; both in their above ground as well as belowground C stocks in the division indicating a skewed age distribution and excessive removal of higher diameter trees in Chir forests between two assessment cycles(Table 2 & 3).

Belowground biomass, Carbon stocks and C density.

The total belowground C stocks of chir forests was estimated to be 98699.56 tonnes during the present study, which constitute a C density of 9.85 t ha^{-1} and 22.48% of total C storage in Chir forests. The below ground C stocks, which stood at 132711.02 tonnes in 1995-96, declined to 98699.56 tonnes by the year 2015-16 thus, reflecting a decline of 34011.46 tonnes in the below ground C storage potential between these two assessment cycles. Associated with this declining trend, the overall belowground C density also decreased to 9.85 t ha^{-1} in 2015-16 from 13.25 t ha^{-1} in 1995-96 registering a decline of 3.40 t ha^{-1}. Further, due to higher number of chir trees in lower diameter classes, the belowground tree biomass as well as its C storage potential also reflect a declining trend in Chir forests of Rajouri division during last 20 years (Table 3).

Temporal variation in Chir stocks and Tree C density (above and below ground)

During 1995-96 assessment, a total of 1330174 Chir trees (132.60 trees/ha) with 1628208.39 m^3 growing stocks in their above ground component were estimated in the division. The chir tree increased to 1978756 (197.61 trees/ha) by 2015-16, however, the growing stocks witnessed a decline to 1210927.80 m^3 registering a decrease of 25.62%. In line with these changes, the Carbon density (above+ below ground), which was 58.95 t ha^{-1} in 1995-96, declined to 43.84 t ha^{-1} in 2015-16, registering a total decrease of 151292.33 tonnes of C stocks in Chir forests during last 20 years (Table 2). Overall , the C stocks (aboveground+ below ground), which stood at 590335.25 tonnes during

Table-3 : Range-wise distribution of trees, growing stock, biomass and C stocks during 1995-96 and 2015-16

Year	Range	Area (ha)	Trees (no.)	Growing stocks (m^3)	Biomass (in tonnes)	Above ground C (tonnes)	Above ground C t ha^{-1}	Below ground C (tonnes)	Below ground C t ha^{-1}	Total Carbon (tonnes)	C t ha^{-1}
1995 -96	Rajouri	4816	678475	742457.10	443989.33	208674.98	43.42	60515.74	12.56	269190.73	55.89
	Kalakote	4344	552472	742169.80	443817.54	208594.24	48.01	60492.33	13.92	269086.57	61.94
	Kandi	853	99227	143581.49	85861.73	40355.01	47.30	11702.95	13.71	52057.96	61.02
	Total	**10013**	**1330174**	**1628208.39**	**973668.60**	**457624.23**	**45.70**	**132711.02**	**13.25**	**590335.25**	**58.95**
2015 -16	Rajouri	4816	951732	582689.22	348448.15	163770.63	34.00	47493.48	9.86	211264.11	43.86
	Kalakote	4344	858457	525081.38	313998.66	147579.37	33.97	42798.01	9.85	190377.39	43.82
	Kandi	853	168567	103157.20	61688.00	28993.36	33.99	8408.07	9.85	37401.43	43.84
	Total	**10013**	**1978756**	**1210927.80**	**724134.81**	**340343.36**	**33.99**	**98699.56**	**9.85**	**439042.93**	**43.84**

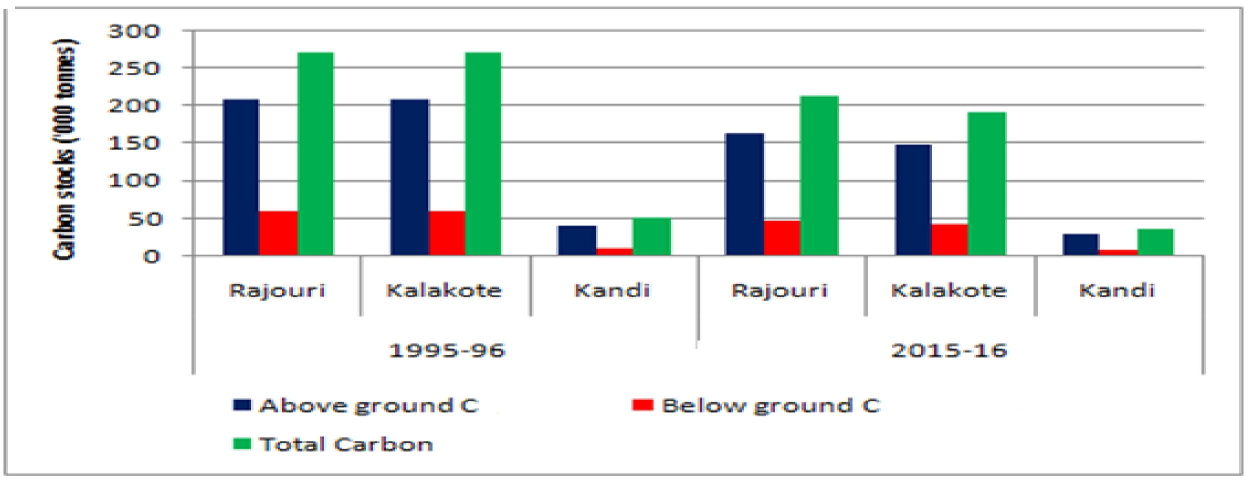


Fig. 3 : Above and below ground C stocks in different ranges.

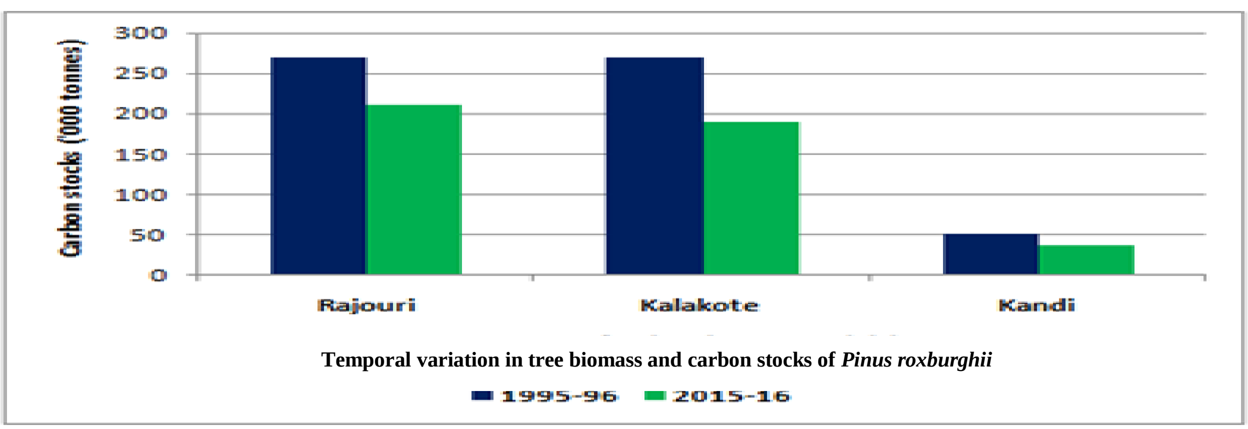


Fig.4 : Temporal variation of carbon stocks in different ranges

1995-96 assessment period, declined to 439042.93 tonnes during 2015-16; the aboveground C stocks declined from 4.57 to 3.40 lac tonnes and below ground C stocks from 1.32 to 0.98 lac tonnes (Figs. 3 & 4). The maximum C is stored in the higher diameter class trees , however, during the present study , it was observed that the major decrease in long term C storage was witnessed in chir trees having diameter classes 40-50 to 80-90 cms (Table 2). Such declining trend s of growing stocks, tree biomass and C storage is also indicative of forest degradation, poor forest health & low C intensity cumulatively attributed to the excessive removal of higher diameter trees, skewed distribution of Chir trees towards lower diameter classes, subdued movement of trees from lower to higher diameter classes and increased anthropogenic pressure on Chir forests of the said division for multiple reasons. Quantifying carbon sources and sinks is a particular challenge in forested ecosystems due to the role played by biogeochemistry, climate, disturbances, heterogeneity of forests and land-use changes. Forest stands accumulate carbon as they progress through successional stages and the greatest rate of carbon uptake occurs during stem exclusion stage (Ashton, *et al*., 2012). However, the carbon sequestration potential differ among different tree species as they widely vary in properties such as growth, mortality, decomposition and their dependency on climate (Purves & Pacala, 2008). In addition to this, the human-induced changes that occur on an annual to centennial time scale are relevant for CO_2 sequestration and play significant role in climate change mitigation. The present study suggest that live tree biomass and C stocks in Chir forests of Rajouri Forest Division have significantly declined during last 20 years; which is cumulatively attributed to multiple factors from forest degradation, excessive removals, sanction of Chir trees to the local concessionists, compulsory felling of forest trees sanctioned under J&K Forest Conservation Act, extraction of fuel wood / firewood from local forests to meet local demands etc. Pertinent to mention, despite a ban on green felling, large numbers of green trees were compulsorily removed in the division between the two inventory periods for above cited factors. Besides felling of 6751 trees (Volume: 839118.19 cft; C stocks 5508.93 tonnes) by the local concessionists (mainly of *Pinus roxburghii* (Chir), another 17278 green trees were felled in the division to undertake different infrastructure developmental projects sanctioned under the Forest Conservation Act during last 13 years. In addition to this, 120261.92 cft of conifer volume was extracted by the State Forest Corporation during the same period to meet the requirement of timber and firewood. Reoccurring forest fires also took its toll to diminish the tree biomass in the division as approximately 45 ha of forest area, primarily chir forests, have suffered from forest fires every year during this assessment cycles. Although the processes and stages involved in forest stand development are well understood, yet there exist considerable unpredictability in actual nature of species assemblage, stock composition and rate of development at each stage due to multiple positive and negative feedbacks. Analysis of density – diameter distribution of particular forest type plays an important role in forest management and formulation of futuristic strategies for sustained growth of forests. The time required to attain a diameter of 30-40 cms in chir forests of Site Quality –II is assessed to be 61 years in Rajouri Forest Division; which appears to have not kept the pace on projected lines. This has been one of the reasons for decline witnessed in tree biomass and C storage potential despite significant increase of chir trees; large number of which added in the lower diameter classes. Further, the skewed number of tree distribution in various diameters have played a major role in such critical shift of growing stocks and C contents of the Chir Forests in Rajouri division. Cumulative effect of all these factors appears to have lowered the highest C storage potential from 50-60cms diameter class trees to lower diameter trees of 40-50cms during the present assessment, which is quite significant. To halt the forest degradation and enhance C intensity of Chir forests, a massive afforestation drive was launched in this division under various centrally sponsored and state schemes. A total of 305.80 lac saplings of different species stands planted in between 2007-08 to 2013-14 covering an area of 2067 ha. However, not only their unsure survival percent, these saplings are likely to take at least 20 to 25 years to establish and sequester significant amount of carbon. Most likely, for the concerted efforts to accord better protection and enhanced conservation measures, significant increase became apparent in Chir trees of Rajouri Forest Division; which from 1330174 in 1995-96 inventory, increased to an estimated number of 1978567 during 2015-16 assessment cycle. But large portion of this addition are yet in lower diameter classes and have years to survive and grow before sequestrating some significant quantum of C in their biomass. Temporal assessment of forest ecosystems become critical to know changes witnessed in forest structure, composition, diameter-wise distribution of stems, annual diameter increment, forest biomass, Carbon stocks, C emissions and their dynamics keeping the extent of degraded and re-growing forests in conifer forests. Collection of vital ground data that accounts for both forest types and ecological conditions is important to improve the understanding of C stocks and fluxes of forests. Hence, periodic estimation of growing stocks of specified forests enable us to assess the extent of changes witnessed in extent, density and composition of the forests over a specific period of time underlining the various ecological factors attributed to such changes. However, where such developments are mainly as a result of human interventions (e.g. wood removals, land-use change, and forest management); spatial and temporal changes are subject to complex interrelations of a variety of factors and agents. The ecologist are often interested in potential functional relationships between forest diversity, C sequestration and storage but a forest scientist, may on the other hand, focus on conservation of such natural resources, ensure their sustainability, record progressive annual increment and dynamics of nutrients. Hence, a comprehensive approach merging these principles shall be ultimately required to meet the broader objectives of scientific management of forests.As per the 5th Assessment Report of IPCC, the atmospheric concentrations of CO_2 are unrelenting increasing, which may alter the C sequestration in forest ecosystems. To counter such erratic changes, Kyoto Protocol provide for off-set credits to Annexure-I industrialized countries (developed nations) under the Clean Development Mechanism (CDM) which allow them to invest in projects that reduce GHG emissions in developing countries. However, the forestry related C gains are limited to afforestation and re-forestation projects only (Plantinga and Richards, 2008). The parties that have signed the UNFCCC and Kyoto Protocol are under an obligation to report their periodic inventories of GHG emissions and removals, including the forest C inventories, as an integral part of periodic reporting mechanism. Hence, such temporal assessments definitely go a long way in meeting twin objectives of knowing the exact availability of forest resource & its C storage potential but also monitor the on-going changes. Nevertheless, an accurate measurement of C stocks and their fluxes dynamics is one of the most important scientific basis for a successful implementation of climate change and carbon policy to fulfill the "Intended Nationally Determined Contribution (INDC's)" commitments besides exploring appropriate opportunities in terms of REDD+ projects to strategies long term parking of forest C stocks in tree biomass through their protection and sustainable management.

Conclusions

Based on the present studies, it is concluded that though Chir forests of Rajouri Forest Division are presently acting as net sink, yet level of their tree biomass and Carbon storage potential has witnessed a significant decline during the last 20 years for multiple anthropogenic activities and sub-optimal management interventions. Management interventions to normalize the skewed tree distribution and avert excessive forest removals shall be critical to ensure sustainability and realize optimal C storage potential of these forests in future.

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