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CARBON STOCK IN STANDING DEAD TREES OF *PINUS ROXBURGHII* SARG. IN SUB-TROPICAL PART OF GARHWAL HIMALAYA

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Abstract

The aim of the present study was to assess the total standing dead trees of Chir pine and their potential of carbon stock in the forests. Chir pine (*Pinus roxburghii*) in Himalayan forest plays a major role in carbon sequestration. Chir pine is a very prominent forest cover in Uttarakhand, out of total 24,414.80 km^2 area under forests; it occupies 3,943.83 km^2 which is 16.15 % of total forest area of the state. In sub-tropical region of Garhwal Himalaya, large numbers of standing dead trees have been observed on southern aspect and increasing continuously last few years. Dead standing (snag) trees in the forest play equal role in carbon sequestration as live trees. Although regular inputs of dead tree components play important role in enrichment of forest floor though litter, twigs, fruits and some time entire tree. The results show that the average standing dead trees were reported 14.83 ha^{-1} of which mean volume and carbon stock values were of 23.14 m^3·ha^{-1} and 14.67 t·ha^{-1} respectively.

Key words: Chir pine, carbon stock, ecosystem services, snag, sub-tropical region.

Introduction

Biomass is a measure of forest structure and function, with both live and dead components. Live biomass through photosynthesis activity sequesters carbon from the atmosphere, whereas, dead biomass retains carbon for longer period even for decades and releasing it gradually by decomposition process (Siccama et al. 2007). Dead trees play a number of important roles in the structure and function of ecosystems (Franklin et al. 1987), provide habitat for organisms (Harmon et al. 1986), influence wildfires (Kauffman et al. 1998), and play roles in carbon and nutrient cycles (Fahey 1983, Krankina and Harmon 1995).

When forests are degraded or cleared, their stored carbon is released into the atmosphere as carbon dioxide (CO_2). Carbon is returned to the atmosphere via three of the largest fluxes: oceanic release (~90 Pg·C·yr^{-1}), plant respiration (~59 Pg·C·yr^{-1}), and soil respiration (~58 Pg·C·yr^{-1}) (IPCC 2000, Luo and Zhou 2006, Houghton 2007, Lambers et al. 2008). Carbon content in plant tissue is approximately half of the dry weight of aboveground live biomass (Malhi and Grace 2000).

Deforestation in the tropics is a major source of carbon emissions and an active contributor to global warming. The Intergovernmental Panel on Climate Change (IPCC) estimated that 1.7 billion tons of carbon is released annually due to land use change, of which the major part is tropical deforestation (IPCC 1995). Tropical deforestation is estimated to have released of the order of 1–2 billion tons of carbon per year during the 1990s, roughly 15–25 % of annual global greenhouse gas emissions (Malhi and Grace 2000, Fearnside and Laurance 2003, Houghton 2005). The largest source of greenhouse gas emissions in most tropical countries is from deforestation and forest degradation. Estimates of emissions from global deforestation range from more than 25 % of global GHG emissions (IPCC 2000), and the vast majority of these emissions are coming from developing countries in the tropics.

Standing and fallen dead trees are the major types of coarse woody residues and their relative contribution to total ecosystem biomass varies greatly in the landscape, depending on forest types, disturbance regimes, topography, and stand age (Spies et al. 1988, Harmon and Hua 1991). Among the multiple functions of coarse woody debris in forest ecosystems, the provision of habitat for many organisms and the long-term storage of carbon and other elements in the forest floor are critical for the maintenance of biodiversity and the continuity of biogeochemical processes (Bowman et al. 2000, McKenny and Kirkpatrick 1999, Harmon et al. 1990, Crowford et al. 1997, Hart 1999, Nakamura and Swanson 1994).

The studies related to soil organic carbon stock of Chir pine have been carried out (Singh et al. 2011, Sheikh et al. 2009) and particularly studies of biomass and carbon stock have also been carried out (Jina et al. 2008, Sheikh et al. 2011) but the studies related to biomass of standing dead trees of Chir pine is completely lacking, particularly in sub-tropical region of Garhwal Himalaya. Therefore, to understand the standing dead trees volumes and carbon available on Chir pine forest, the following objectives were selected: (i) to estimate the volume of standing dead trees of Chir pine forest and (2) to estimate the total carbon stock (above and below ground) of standing dead trees of Chir pine forest.

Material and Methods

Study area

The study was carried out in Chir pine forests (Fig. 1) of sub-tropical region of Garhwal Himalaya in Tehri Garhwal district of Uttarakhand. Three different sites of Chir pine forest were selected for study each of 4, 6 and 7 hectares patches. The Chir pine dead trees were observed only in southern aspect and none of them were observed in other aspects. Therefore, enumeration of trees was done from southern aspect. Chir pine dead trees in the selected sites were enumerated for volume and carbon stock assessment.

The study sites are located between 30°28.179′–30°28.189′ N latitude and 78°27.338′–78°27.700′ E longitude at 1100, 1200 and 1250 m a.s.l. The climate of the study area is quite distinct in a year and represents three different marked seasons, i.e. summer, winter and rainy. The climate is influenced by monsoon pattern of rainfall. The winter is very cold with minimum temperature dropping to 4 °C (December) and during summer temperature reaches up to 32 °C (June). The average annual rainfall reported 1000 mm and approximately 75 % rainfall is received from mid-June to mid-September. The relative humidity varies from 35 % (May) to 92 % (August).

a

b

c

d

Fig. 1. Dead standing trees in natural Chir pine forest sites: a – close view of forest; b – large number of dead trees in small patch; c – young dead trees; d– falling branches of dead trees.

Data collection

Carbon estimation of Chir pine dead standing trees in each site was carried out by complete enumeration basis. The data was collected for diameter at breast height (1.3 m) of individual tree, using tree caliper for the estimation of growing stock volume density (GSVD) following volume equations of Forest Research Institute and Forest Survey of India publications for Chir pine (FSI 1996, Sharma et al. 2010). The estimated GSVD ($m^3 \cdot ha^{-1}$) was fur-

Table 1.Volume and carbon stock in standing dead Chir pine forest at three different sites.

Site	Aspect	Altitude, m a.s.l.	Dbh, cm	Height, m	Dead trees, ha^{-1}	Volume, $m^3 \cdot ha^{-1}$	AGC, $t \cdot ha^{-1}$	BGC, $t \cdot ha^{-1}$	Carbon stock, $t \cdot ha^{-1}$
I	Southern	1100	45	22.91	11.00	16.39	7.785	2.61	10.39
II	Southern	1200	46	19.97	17.75	28.53	13.55	4.46	18.01
III	Southern	1250	45	20.97	15.75	24.51	11.64	3.97	15.61
Mean			45.3	21.28	14.83	23.14	10.99	3.68	14.67

ther converted into aboveground biomass density (AGBD) of tree components (stem, branches, twigs and leaves), which was calculated by multiplying GSVD of the Chir pine forest with appropriate biomass expansion factor (BEF) (Brown et al. 1999). The belowground biomass density (BGBD; fine and coarse roots) for Chir pine forests were estimated using Cairns et al. (1997). Above ground carbon and below ground carbon was estimated by using the co-efficient of 0.50 for conversion from biomass to carbon stocks (Brown and Lugo 1982, Roy et al. 2001, Malhi et al. 2004). The above ground and below ground carbon was added to estimate total carbon of standing dead trees of Chir pine in each site.

Results and Discussion

The carbon stock of Chir pine dead standing trees in different sites is shown in Table 1. The highest numbers of standing dead trees (17.75 trees ha^{-1}) were recorded in site II followed by site III (15.75 trees ha^{-1}) and site I (11 trees ha^{-1}). The maximum and minimum volume of Chir pine trees were 28.53 $m^3 \cdot ha^{-1}$ and 16.39 $m^3 \cdot ha^{-1}$ for site II and site I respectively (Table 1). Carmona et al. (2002) reported the volume of snags (14–924 $m^3 \cdot ha^{-1}$) for temperate forests in Chiloe Island, Chile. The ranged value of above ground carbon of standing dead Chir pine was 7.785 $t \cdot ha^{-1}$ to 13.55 $t \cdot ha^{-1}$ (Table 1). The maximum below ground carbon was 4.46 $t \cdot ha^{-1}$ followed by 3.97 $t \cdot ha^{-1}$ and 2.61 $t \cdot ha^{-1}$ for site II, site III and site I respectively. The maximum (18.01 $t \cdot ha^{-1}$) total carbon of Chir pine trees was recorded in site II followed by site III (15.61 $t \cdot ha^{-1}$) and site I (10.39 $t \cdot ha^{-1}$) (Table 1). A study carried out by Oswalt et al. (2008) in Caribbean St. John, U.S. Virgin Islands reported that dead woody materials contributed an estimated 16 percent (8.9 $mg \cdot ha^{-1}$ ± 0.8) of the total aboveground and belowground carbon, however, total standing dead tree (snag) basal area ranged from 0.0 to 1.3 $m^2 \cdot ha^{-1}$. In the present study, it was observed that southern aspect was more susceptible for increasing number of dead Chir pine trees, might be due to this aspect receiving more sun light intensity which is comparatively drier of other aspects result in it may also change the soil physico-chemical properties, which may lead to favourable environment for pathogens. Guarın and Taylor (2005) reported that the temporal patterns of tree death were reported similar on north facing and south facing slopes but, the density of dead trees was higher on north facing slopes than south slopes.

In the present study, when bark from Chir pine dead trees was removed, termite attack below tree bark was observed, which could be another reason for dead trees. A study shows that epidemic tree deaths further exacerbate global warming because the forest changes from a net carbon sink to a carbon source, as the dead trees can no longer absorb carbon dioxide and release tons of the greenhouse gas (Jim Agar 2008).

Altitude was negatively correlated with volume, above and below ground carbon of standing dead Chir pine trees. Volume of standing dead trees was significantly positive correlated with below ground carbon and total carbon stock at 5 % level. Above ground carbon of standing dead Chir pine trees were correlated perfectly positive with volume. Total carbon stock was also significantly correlated ($p < 0.05$) with above and below ground carbon of standing dead trees of Chir pine.

Deadwood plays a key role for sustaining forest productivity and environmental services such as stabilizing forests and storing carbon by its biodiversity. Volume of deadwood depends on productivity, pattern of natural disturbance, succession stages, forest history and human intervention. Deadwood type and volume vary between different forest types and management systems. Some disturbance has linked to the production standing deadwood (e.g. dry-out), or fallen deadwood (e.g., storm damage). Both downed and standing dead wood store carbon are important components of forest carbon dynamics but also release carbon via decomposition and combustion in fires. A study carried out by Domke (2011) in the U. S. for estimate changes in the standing dead tree biomass and carbon stock and the results suggest that density reductions and structural loss in standing dead trees substantially decreases estimates of standing dead tree biomass and carbon at tree, plot, and regional scales. Pugh and Gordon (2012) carried out a study in a regions of western North America with snow-dominated hydrology, the presence of forested watersheds where, widespread tree death in these watersheds can dramatically alter many ecohydrological processes including transpiration, canopy solar transmission and snow interception, sub-canopy wind regimes, soil infiltration, forest energy storage and snow surface albedo.

In Europe species associated with deadwood now make up the largest single group of threatened species. Of the 1,700 species of invertebrates in the UK dependent for at least part of their life cycle on deadwood, nearly 330 are Red Data Book-listed because they are rare, vulnerable or endangered (Smith 2004). In Sweden, one of the most densely forested countries in Europe, 805 species dependent on deadwood are on the national Red List (Sandström 2003). Major forest carbon pools include trees, understorey vegetation, deadwood, litter, and soil. Deadwood is important as it is both a store and source of carbon. This will now change because national carbon inventories are required under the Kyoto Protocol of the 1992 United Nations Framework Convention on Climate Change (Woldendorp 2002). Deadwood releases carbon to the atmosphere during microbial respiration from decomposer organisms and are the source of carbon. In cool climates, microbial activity is restricted and decomposition very slow and deadwood remain for long-term storage on site becomes a source of carbon stock for long period.

The dead standing trees, fallen components of trees helps in maintaining environmental carbon. Live biomass sequesters carbon through photosynthesis from the atmosphere, whereas dead biomass can retain carbon for decades, releasing it gradually by decomposition (Siccama et al. 2007, Kim 2009). Live and dead components affect many aspects of forest ecology. Because wildlife species require varying amounts and spatial arrangements of live and dead biomass (McCarney et al. 2008, Kim 2009). But from the study area has been observed that the branches and some time entire tree are used by the local villagers for fuelwood purposes. It has also been observed that Chir pine forest are prone to fire and damage large amount of residual of forest floor after fire and become source of environmental CO_2. It has observed from the study sites that the forests are normally affected every year by fire. These forests become extremely vulnerable to fires when they are located on dry sites (Kumar et al. 2013), which due to course of time may be affected by certain termite or beetle attack and die. It is evidence from the earlier studies (Fowler and Sieg 2004, Parker et al. 2006) that fire-damaged or drought-stressed trees are generally attacked by bark beetles. Droughts, wildfires, and insect and disease outbreaks have left large numbers of standing dead and dying trees in western forests. Forest inventories conducted by the U.S. Department of Agriculture Forest Service estimate the average annual mortality volume (i.e., the volume of wood in the trees that die or are killed each year by natural causes) to be about 2,500 million cubic feet (USDA FS 2005, 2006). Management of these dead and dying trees, in particular post fire salvage, is controversial (Peterson et al. 2009).

Thus the human interference affect the natural decomposition process of trees is forest floor and further affect nutrient release and carbon storage from the fallen and standing dead trees. Therefore, special strategies need to be done on government level, village community level to aware the people for maintaining these standing dead trees and even after fallen trees in the forest floor for long term carbon sequestration and ecosystem services.

Conclusion

The study suggests that the dead trees have potential in carbon sequestration. After falling these dead trees and their components also enrich forest floor. The process of further decomposition of dead trees and its components cannot be avoided. But some time these trees are cut and used by villagers for fuelwood and other purposes, which directly affect the natural process of enrichment of forest floor and the potential of carbon sequestration. Therefore, the awareness of villagers about its effect on forest floor and direct emission of gases through use of fuelwood can be minimized.

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