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Carbon stocks and fluxes for forests in Odisha (India)

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Abstract: Reducing carbon emissions from deforestation and forest degradation (REDD) is expected to play key role in mitigating climate change. In this context, forest carbon inventory at national level and state/regional levels is essential. In this paper, we have estimated the total carbon stocks in forests of Odisha state in India i.e. 444.05 Mt, consisting of 159.76 Mt as biomass and 284.29 Mt as soil organic carbon. Forest carbon fluxes have been estimated using *Gain-Loss* methodology as per IPCC (2006) guidelines. For the reference year 2008 - 09, the annual carbon gain through primary productivity was estimated at 5.240 Mt, and the loss of carbon on account of wood-firewood removals, forest fires, and land-use change, was 0.139 Mt resulting in net accumulation of 5.101 Mt of carbon. State level estimates of total carbon stock and CO_2 emissions and removals are necessary, since in India state level climate change action plans are being prepared.

Resumen: Se espera que la reducción de las emisiones de carbono derivadas de la deforestación y la degradación de los bosques (REDD) juegue un papel clave en la mitigación del cambio climático. En este contexto, es esencial contar con inventarios de carbono forestal a nivel nacional y estatal/regional. En este trabajo estimamosque las reservas totales de carbono en los bosques del estado de Odisha en la India son de 444.05 Mt, cifra que incluye 159.76 Mt como biomasa y 284.29 Mt como carbono orgánico del suelo. Se estimaron los flujos de carbono forestal usando la metodología de Pérdidas-Ganancias de acuerdo *con los* lineamientos del IPCC (2006). Para el año de referencia 2008 - 09, se estimó que la ganancia anual de carbono por medio de la productividad primaria fue de 5.240 Mt, y que la pérdida de carbono debida a la extracción de madera y leña, los incendios forestales y el cambio de uso del suelo fue de 0.139 Mt, lo que resultó en una acumulación neta de 5.101 Mt de carbono. Es necesario contar con estimaciones a nivel estatal de las reservas totales de carbono, así como de la emisión y absorción de CO_2, ya que en la India se están preparando planes de acción sobre el cambio climático a nivel estatal.

Resumo: A redução das emissões de carbono por desmatamento e degradação florestal (REDD) é esperado que jogue um papel fundamental na mitigação das mudanças climáticas. Neste contexto, o inventário do estoque de carbono florestal a nível nacional e regional é essencial. Neste trabalho, estimamos os estoques totais de carbono em florestas do estado de Odisha, na Índia, ou seja, 444,05 milhões de toneladas, repartido por 159,76 Mt como biomassa e 284,29 Mt como carbono orgânico no solo. Os fluxos de carbono florestais foram estimadas usando a metodologia Ganho-Perda conforme as diretrizes do IPCC (2006). Para o ano de referência de 2008 - 09, o ganho anual de carbono através da produtividade primária foi estimado em 5,240 milhões de toneladas, e a perda de carbono por conta das remoções de lenha, incêndios florestais, e mudança no uso da terra, foi 0,139 Mt, de que resulta um acúmulo líquido de 5,101 milhões de toneladas de carbono. Estimativas estaduais do estoque total de carbono, de emissões e remoções de CO_2 são necessárias, uma vez que na Índia, ao nível estadual, estão sendo preparados planos de ação para as mudanças climáticas.

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Key words: Carbon stocks, carbon fluxes, carbon pools, gain-Loss method, vulnerability, Odisha forests.

Introduction

The rapid accumulation of carbon dioxide and other green house gases (GHGs) in the atmosphere is projected to cause observable significant climate change. Carbon dioxide is the major greenhouse gas (GHG) and about 60 % of the observed global warming is attributed to increase in its concentration in the atmosphere (Grace 2004). The concentration of carbon dioxide in the atmosphere has increased from 280 ppm in 1750 to about 400 ppm now largely as a result of use of fossil fuel for energy production, cement production, and, deforestation and forest degradation (IPCC 2007a).

Forests are uniquely placed in the whole scenario of climate change as they are a sink as well as source of carbon dioxide. They store large quantities of carbon in vegetation and soil, exchange carbon with the atmosphere through photosynthesis and respiration, and act as sources of atmospheric carbon if they are disturbed by some human activities (e.g., harvesting, clear cutting for conversion to non-forest purposes, poor harvesting procedures) or natural causes (Haripriya 2003). Forest sector is also closely linked to socio-economic systems, particularly the livelihoods of forest-dependent communities and are likely to be adversely impacted under climate change due to change in atmospheric concentration of carbon dioxide and other GHGs (Murthy *et al.* 2012).

Forests play an important role in the global carbon cycle and the estimated carbon stocks in forests and forest soils is about 2150 GtC, which is thrice the atmospheric carbon pool of 750 GtC (IPCC 2000). They are one of the world's major carbon stores, containing about 80 % of above-ground terrestrial biosphere carbon and 40 % of terrestrial below-ground carbon (Krischbaum *et al.* 1996). Carbon fixed in plants by photosynthesis and added to soil as above and below ground litter is the primary source of carbon in ecosystems (Warembourg & Paul 1977). Undisturbed forest ecosystems are generally highly productive and accumulate more biomass and carbon per unit area compared to other land use systems like agriculture (Devagiri *et al.* 2013). Also, forests contribute about 17.4 % of the total GHG emissions (IPCC 2007b). As a result, forests are at the centre stage of global negotiations under United Nations Framework Convention on Climate Change (UNFCCC), and the Intergovernmental Panel on Climate Change (IPCC) has recognized the significant opportunity that forests provide as 'carbon sink'.

Kyoto protocol to the convention (UNFCCC) explicitly considered reforestation and afforestation activities for carbon sequestration. Further, during the 13th Conference of Parties (COP) at Bali in 2007, the need to evolve mechanism for incentivizing avoided deforestation and forest degradation was agreed to. This approach is referred to as REDD (Reducing Emissions from Deforestation and forest Degradation) approach. India, along with other like-minded countries that have creditable tradition of forest conservation, proposed REDD+ approach, which includes conservation of forests, sustainable management of forests and enhancement of carbon along with avoided deforestation and forest degradation. In this scenario it becomes important to maintain a periodic inventory of carbon stocks and fluxes for forests as baseline scenario. The rationale for estimating the carbon stock and fluxes is the need to develop state level climate change action plans in India. Such an exercise is further supported by the need for information about status of forest carbon density, which is an indicator of ecosystem productivity and associated ecosystem services. Further, the information on carbon fluxes from forests is required for national greenhouse gas inventory preparation and communication under UNFCCC processes. Moreover, conservation of carbon stocks and flux monitoring and management are part of mitigation strategy. Accordingly in the present study, the total carbon stock and the annual carbon fluxes have been estimated for forests of Odisha state for the reference year 2008 - 09.

According to the Forest Survey of India (FSI) all lands, more than one hectare in area, with a tree canopy density of more than 10 % is defined as Forest (FSI 2009). The forest cover in the state, based on interpretation of satellite data of October 2008 - January 2009, is 48,903 km^2 which is 31.41 % of the state's geographical area.

As per the forest classification by Champion & Seth (1968), the state has 18 forest types belonging to four forest type groups, viz. Tropical Semi

Evergreen Forest (TSF), Tropical Moist Deciduous Forest (TMF), Tropical Dry Deciduous Forest (TDF) and Littoral & Swamp Forests (LSF). Percentage-wise distribution of forest covers in different type groups reveals that Tropical Dry Deciduous Forest (57.87 %) is predominated followed by Tropical Moist Deciduous Forest (39.88 %), Plantations (1.09 %), Tropical Semi evergreen Forest (0.68 %) and Littoral & Swamp Forests (0.48 %).

Methodology

We have followed the 2006 guidelines issued by the IPCC for estimating greenhouse gas inventories contained in Volume 4 (Agriculture, Forestry and other Land Use) to arrive at carbon stocks and carbon fluxes for the forests of Odisha state. Based on the criteria given in the *decision tree* (Figure 1.2, Volume 4) for *land remaining in the same land-use category*, in the guidelines, Tier 1 methodology was feasible to adopt in the present study. Tier 1 level methods are appropriate when the region specific spatially fine data is not available and, therefore, use of default values for different parameters is the only option. The default parameter values are given in the guidelines and these are based on much coarser data. Odisha specific parameter values are not available. However, values for some parameters like *below-ground biomass to above-ground biomass ratio* and *leaf litter biomass carbon* are available at country level - the same have been used in the present study to improve the level of approximation.

Carbon pools

IPCC (2003, 2006) has defined five carbon pools for green house gas inventory. They are

(1) Living biomass
  (a) Above-ground
  (b) Below-ground (roots)
(2) Non-living biomass
  (a) Litter
  (b) Deadwood
(3) Soil organic carbon

Here, we have followed the above mentioned five carbon pools for estimating pool strength and carbon fluxes in forest landscapes. Under live biomass pool, carbon in above and below-ground biomass is estimated. Above-ground biomass includes woody and herbaceous biomass above soil. However, under the present study only woody biomass has been considered primarily for lack of estimates for herbaceous biomass. Below-ground biomass consists of all root biomass. Under non-living pool, deadwood and litter are included. Dead wood includes all dead woody biomass above and below-ground that is above 10 cm in diameter, while litter consists of dead biomass above or below-ground that is less than 10 cm and more than 2 mm in size. Soil organic matter consists of above-ground dead organic matter that is less than litter size and below-ground live organic matter that is less than 2 mm in size. As also suggested in the guidelines a default depth of 30 cm (most fine roots are confined to this shallow depth: Ravindranath & Ostwald 2008) has been considered in the present study to estimate the strength of soil organic carbon pool.

Source of parameter information for different carbon pools

The source of information on various parameters to estimate the above-mentioned pools of carbon is given in Table 1.

(A) The carbon stocks have been estimated in Above Ground Biomass (AGB), Below Ground Biomass (BGB), Dead Wood Biomass (DWB), Litter Biomass (L) and Soil Organic Carbon (SOC) up to 30 cm depth. To estimate the carbon stocks volume-based approach was adopted and the growing stock figures reported by the *Forest Survey of India* in the *India State of Forest Report (2011)* were used. Following equations are used to calculate the total carbon stocks:

$C_T = C_{AGB} + C_{BGB} + C_{DWB} + C_L + C_S$
C_T = Total C
C_{AGB} = Quantity of C in above-ground biomass
C_{BGB} = Quantity of C in below-ground biomass
C_{DWB} = Quantity of C in dead wood biomass
C_L = Quantity of C in litter biomass
C_S = Quantity of C in soil up to 30 cm depth
$C_{AGB} = GS \times BCEF_S \times CF$

GS is volume of merchantable wood; $BCEF_s$ is *Biomass Conversion and Expansion Factor* for conversion of growing stock to total above-ground biomass - 0.8 (Table 4.5, Chapter 4, Volume 4, IPCC Guidelines 2006) and 0.7 in humid tropics when GS is more than 200 m^3 ha^{-1} CF is carbon density factor (country average CF of 0.4524 adopted from Chhabra & Dadhwal 2004).

$GS_{BGB} = 0.26 \times GS_{AGB}$ (BGB to AGB ratio factor of 0.26 used : Cairns *et al.* (1997) arrived at a mean of 0.26 with a range of 0.18 - 0.3 on the basis of 160 studies from tropical, temperate and

Table 1. Carbon pools and source of information.

Land-use category	Subcategory	Carbon pools	Source of parameter information	Parameter value
Forest land	Forest land remaining forest land	Above-ground biomass (AGB)	From the total GS figure for Odisha reported by FSI in SFR 2011	Total GS = 285.191million m^3
		Below-ground biomass (BGB)	Default value from IPCC guidelines	BGB/AGB = 0.26
		Leaf litter biomass	Country specific information	3.271 t C/ha (Chhabra & Dadhwal 2004)
		Dead wood biomass (DWB)	Default value from IPCC guidelines	Above-ground DWB/AGB = 0.11
		Soil C	Country specific information	Adopted from Ravindranath *et al.* 1997

boreal forests - it may be practical to use mean value of 0.26 for arriving at root biomass (Ravindranath & Ostwald 2008).

$C_{DWB} = 0.11\ (C_{AGB} + C_{BGB})$

0.11 is IPCC default factor for tropical forests.

For the C content of litter the country-average of 3.271 tC per ha (Chhabra & Dadhwal 2004) has been used.

(B) The annual carbon flux has been estimated by carbon-gain from biomass increment in forests and carbon-loss due to timber and firewood removals, forest fires and diversion of forest-land. The annual increment was calculated using the increment rate of biomass reported in the published literature (Ravindranath *et al.* 1997). The data on annual timber and firewood harvest, area affected by fire, and the extent of forest area diverted for other than forest purposes is sourced from the record of the Odisha Forest Department (OFD) and Forest Survey of India Report (2011).

$C_i = C_{iAGB} + C_{iBGB}$

C_i = Annual C increment

C_{iAGB} = Annual C increment in live above-ground biomass

C_{iBGB} = Annual C increment in live below-ground biomass

$C_{iBGB} = 0.26 \times C_{iAGB}$

The loss of carbon due to *removal of wood and firewood* from forests of Odisha state has been considered as equal to the total round wood production during the year 2008 - 09. The lops and tops that are not measured as they are collected by the locals to meet their day-to-day firewood needs. The removal of carbon on account of harvest of non-timber forest products including bamboo has not been considered in the present study.

$L_{Wood\text{-}Firewood} = H \times BCEF_R \times (1+R) \times CF$

H is volume of annual wood-firewood removal; $BCEF_R$ is *Biomass Conversion and Expansion Factor* for conversion of wood-firewood removal to above-ground biomass – *0.89* when full tree is removed (Table 4.5, Chapter 4, Volume 4, IPCC Guidelines 2006) and *1.05* for natural forests in humid tropics where GS is more than 200 m^3; CF is carbon density factor; R is below-ground biomass to above-ground biomass ratio (R = 0; Tier 1 method).

For *loss of carbon due to fire from forests* in Odisha state, only the areas impacted by wild fires and not those burnt as pre-burning of forest areas (prevailing management practice to avoid large scale more destructive wild fires later in the season) have been considered. For forest fires in Odisha state, it is safe to assume that all fires are ground fires. Further in the extreme case all the dead wood and litter biomass available on the forest floor is likely to be lost. In the present study for the area impacted by fire, it is assumed that all the above-ground dead wood and litter biomass carbon is lost.

$L_{Fire} = L_{Above\ ground\ DWB} + L_{Litter}$

$L_{Above\ ground\ DWB}$ = Loss of carbon from above-ground dead wood biomass

L_{Litter} = Loss of carbon from litter

For the *forest area diverted for non-forestry purpose,* it is assumed that the carbon from all the pools above-ground is lost during the year of diversion itself and nothing is added to dead wood pool and litter pool (Tier 1 methodology). Practically however, this may not be the fact since

Table 2. Growing stock based estimation of total carbon content in the biomass pools for Odisha forests.

Carbon pool	Growing stock (million cum)	Dry biomass (Mt)	Total C (Mt)
Above-ground Biomass (AGB)	285.191	228.15	102.86
Below-ground Biomass (BGB)	^74.14	59.31	26.69
Dead Wood Biomass (above and below-ground)	*39.52	31.61	14.22
Litter	-	-	15.99
			159.76

^derived as 26% (default value by IPCC) of AGB: *derived as 11% (default value by IPCC) of total of AGB and BGB.

only a portion of vegetation from such lands may be removed during the year of diversion or some portion of original vegetation is never removed. The carbon fluxes calculated under above-mentioned assumptions provide estimates for maximum carbon-loss scenario from these removals/disturbances.

$C_{DFL} = A_d \text{ x } (C_{AGB} + C_{BGB} + C_{DWB} + C_L + C_{Soil})$

C_{DFL} = C lost from area of forestland diverted

A_d = Area diverted (ha)

C_x = Per hectare carbon density in pool: x is AGB, BGB, DWB, Litter and Soil

The net gain in carbon for the reference year 2008-09 = $\Delta C_G - \Delta C_L$

where, ΔC_G = Annual gain in carbon in 2008 - 09

ΔC_L = Annual loss in carbon in 2008 - 09.

Results and discussion

This is the first attempt to estimate both, carbon stocks and fluxes for Odisha state. The estimates have been made for the reference year 2008 - 09 as the latest growing stock figures from Forest Survey of India are available for 2008 - 09 in the *India State of Forest Report (2011).* Here we have estimated the total carbon stock in forests of Odisha state at 444.29 Mt (Million ton) consisting of 159.76 Mt as biomass carbon and 284.29 Mt as soil organic carbon up to 30 cm depth. The total carbon in the biomass pools has been estimated based on growing stock (volume-based approach) (Table 2).

Chhabra & Dadhwal (2004), as part of their country level study, adopted volume-based approach and estimated total phytomass carbon for Odisha forest as 270 Mt (for 1993) distributed over 4.71 Mha of forest area at an average of 57.32 t ha^{-1} phytomass carbon density. Based on the total phytomass carbon of 159.76 Mt, we have calculated phytomass carbon density of 32.66 t ha^{-1}. The reason for this difference may be that while we have adopted much lower average canopy cover values (Table 4), they considered the forests under only three canopy cover classes namely, very dense (> 70 %), dense (40 - 70 %) and open forests (< 10 %), which is a coarser approximation and depending upon the area considered under each canopy cover classes, would result in higher growing stock estimation and hence the higher carbon density.

Forest-type wise soil organic carbon in top 30 cm of soils for Indian forests reported in the literature (Ravindranath *et al.* 1997) is available and the same has been adopted to arrive at the total soil organic carbon. In case of plantations, low soil carbon value of 44 t ha^{-1} reported for tropical thorn forest has been assumed since plantations are raised in degraded forest areas with eroded soils. The soil organic carbon was estimated in the top 30 cm soil layer for the Odisha forests with average density of 58.13 t ha^{-1}. The details of the same are given in Table 3.

Productivity and annual C uptake

The annual productivity rates for different forests have been adopted from Ravindranath *et al.* (1997) to arrive at the annual sequestration of carbon. The annual above-ground carbon gain by forests of Odisha has been estimated as 4.159 Mt (Table 4). Further adopting a ratio of 0.26 between belowground and above-ground biomass for productivity, the gain in below-ground biomass carbon is estimated as 1.081 Mt. The total annual incremental carbon in live biomass in Odisha forests adds to 5.240 Mt.

The C losses due to disturbances

Removal of wood-firewood, land-use change of

Table 3. Soil organic carbon in top 30 cm of soil.

Forest type	Area (ha)	^Average soil carbon in top 30 cm' (t/ha)	Total organic carbon content in top 30 cm soil (Mt)
Tropical Semi Evergreen	33254.04	171.75	5.71
Tropical Moist Deciduous	1950251.64	57.14	111.43
Tropical Dry Deciduous	2830016.61	57.99	164.11
Littoral and Swamp	23473.44	30.22	0.70
Plantations	53304.27	44.00	2.34
Total forest area (hectare)	4890300.00		284.29

(^Adopted from Ravindranath *et al.* 1997).

Table 4. Total annual above-ground carbon gain by Odisha forests.

Forest type	Area (ha)	Standing biomass (at canopy cover = 1) (t/ha)	*Average canopy cover (%age)	Total standing biomass (Mt)	*% NPP (as % of the Standing biomass)	Total annual woody biomass accumulation (Mt)	Total annual C gain (Mt)
Tropical Semi Evergreen	33254.04	468	0.478	7.43	1.28	0.095	0.042
Tropical Moist Deciduous	1950251.64	409.3	0.426	340.04	1.46	4.964	2.23
Tropical Dry Deciduous	2830016.61	115.5	0.431	140.87	2.84	4.0	1.8
Littoral and Swamp	23473.44	213.8	0.442	2.21	4.34	0.095	0.042
Plantations	53304.27	32	1.000	1.70	6.0	0.102	0.045
Total	4890300.00					9.193	4.159

*Ravindranath *et al.* 1997 and Komiyama *et al.* 2008.

forest lands to non-forest purposes like for development projects and forest fires constitute major disturbances that result in substantial loss of carbon from forests in Odisha state. For the reference year 2008 - 09, the total round wood production is estimated to be 0.029 m cum (FSI 2011 Report). Taking the Biomass conversion and expansion factor- 0.89, the total carbon loss from round wood production is found to be 0.011 Mt (Table 5). Further, the Tier 1 methodology assumes that there is no change in organic soil carbon stock during any particular year as the soil organic carbon is in steady state i.e. loss of carbon by the soil during an year is equal to carbon gained by the soil during the same period.

Forest fire

As per the records of the Odisha Forest Department, during the year 2008 - 09, fires in 1251 incidents affected 1057.99 hectare of forest area. These fires that were limited to forest floor are called ground fires and they do not result in death of a forest stand. They, however, can potentially consume all the biomass fuel available on the forest floor and adversely impact standing trees, soil-moisture regime and regeneration status. Estimation for the area, which was subjected to pre-burning as management practice to avoid larger and more intense fires during the peak fire season, is not available for 2008 - 09. For the purpose of present study, the carbon loss calculations are based on the premise that all above-ground dead wood and litter biomass is lost due to fires from 1057.99 hectare of forest area during the fire season in 2008 - 09. The carbon loss due to forest fires has been estimated as 0.005 Mt (Table 6).

Land-use change

The information about the extent of *forest land diverted for non-forest use* was sourced from the

Table 5. Total round wood production (in m^3) from Odisha forests during 2008-09.

Total round wood production (m cum)	$BCEF_R$	Biomass (Mt)	Total carbon (Mt)
0.029	0.89	0.025	0.011

$BCEF_R$: Biomass conversion and expansion factor for wood-firewood

Forest Department, Bhubaneswar, quoted in CPSW, State of Orissa's Environment- A citizen's Report, Bhubaneswar, 1994. We have taken the average value of the rate of diversion of forest land for last 20 years (1980 - 2000). The average extent of forest land diverted is 1269.68 ha yr^{-1}. The total carbon loss from such areas has been estimated at 0.123 Mt (Table 7). This is an overestimation owing to the assumed premise that all carbon from all pools including soil pool is lost and that too in the year of diversion itself.

Vulnerability of Odisha forest carbon stocks under climate change

Chaturvedi *et al.* (2011) have assessed the impact of climate change on forests of India including for Odisha state using IBIS v.2 dynamic vegetation model and have reported that forests in Odisha state are likely to be among least vulnerable forests in the country under A1 as well as B2 emission scenarios during the present century, and this is on account of high diversity, low fragmentation, high tree density and low rate of forest vegetation change. And also that, Odisha forests are likely to be benefited by increase in NPP from lower warming and increase in precipitation. Gopalakrishnan *et al.* (2011a) have studied teak forests at species level and reported that forest grids dominated by Teak species in Odisha state are not vulnerable under A1 and B1 scenarios. However, even within this overall scenario, out of the total number of 2564 (2.5 x 2.5 minute) forest grids that fall in Odisha state, 9.71 % and 13.53 % of the grids are projected to undergo change by the year 2035 and 2085, respectively (Gopalakrishnan *et al.* 2011b). Such projected change in forest grids (which means change in present vegetation since the future climate is not likely to be suitable for it) is indicative of high carbon flux activity at local level, which has implications for REDD+ initiatives and carbon stocks.

Alongside this projected biophysical response of Odisha forests, the anthropogenic pressure on forests due to removal of round-wood and fuel-wood, incidents of fire, land-use change to non-forest purposes, cattle grazing etc., which result in forest carbon loss also needs to be considered and mechanisms that ensure avoiding such loss must be established for securing forest carbon. Formally engaging local communities in protection, development and conservation of forests provides such an opportunity. By June 2011, 19.76 % (1.148 million hectare) of notified forest area in Odisha state was under joint management between 12,494 local community institutions at village level (called *Van Samrakshyana Samity*) and Odisha Forest Department (ICFRE 2011). This process is harmonizing the unregulated usage of forest by addressing demand-supply situation, and the communities are taking over the role of planner, manager, user and regulator of the forest resource. This forest-securing mechanism is likely to be operationalized over remaining forest areas in Odisha state, which is likely to set up a carbon-conservation regime that would develop carbon-consciousness in use of forest products and forestland. Also, the Climate Change Action Plan developed by the Government of Odisha is an important document setting direction for necessary mitigatory and adaptation actions to be taken in all the relevant sectors of development including forestry, which is further likely to address the vulnerability issue in respect of forest carbon stocks.

In view of the above, forest carbon stocks in Odisha state appear largely secured, however, this inference could be only as certain as the projections about climatic changes, the actual turn out of community involvement mechanism, and implementation of the other mitigation-adaptation actions proposed in the climate change action plan.

Conclusions

In the present study, the total carbon stock in forests in Odisha has been estimated to be 444.05 Mt with 159.76 Mt in biomass and 284.29 Mt in soil up to 30 cm depth. For the year 2008 - 09, it has been estimated that while the annual carbon gain was 5.240 Mt, the loss of carbon on account of wood-firewood removals, forest fires, and land-use change was 0.139 Mt resulting in net accumulation of 5.101 Mt of carbon. The carbon balance for forests of Odisha has been in favour of

Table 6. Carbon loss from forest area impacted by fire in Odisha in 2008 - 09.

Year	Extent of forest area affected by fire (ha)	Average dead wood biomass (t/ha)	Total carbon loss due to burning of dead wood matter (t)	Average litter carbon content (t/ha)	Total carbon loss due to burning of litter matter (t)	Total carbon loss due to burning of dead wood and litter matter (Mt)
2008-09	1057.99	9.055	0.004	3.271	0.001	0.005

Table 7. Loss of carbon from forest land diverted for non forest purpose in 2008 - 09.

Extent of area diverted during 2008-09 (ha)	Growing stock carbon density for Odisha (t/ha)	Carbon loss from growing stock (Mt)	Carbon loss from dead wood (Mt)	Carbon loss from litter (Mt)	Soil carbon density for Odisha (t/ha)	Carbon loss from soil 30 cm (Mt)	Total carbon loss (Mt)
1269.68	32.66	0.041	0.004	0.004	58.29	0.074	0.123

Table 8. Loss of carbon from forest land diverted for non forest purpose in 2008 - 09.

Carbon pools	Quantity of carbon (Mt)
Total biomass carbon	159.76
Total soil carbon up to 30 cm depth	284.29
Total carbon stock in Odisha forests	444.05
Annual carbon gain by primary productivity	5.240
Annual carbon loss	
a. Annual carbon loss due to wood-firewood removal	0.011
b. Annual carbon loss due to forest fire	0.005
c. Annual carbon loss due to land-use change from forests	0.123
Total annual carbon loss from disturbances	0.139
Net carbon balance for forests in Odisha during 2008-09	*'Sink'* = 5.101

sink during 2008 - 09. The projected climatic conditions for Odisha state, and wide implementation of the community-based participatory forest management approach, suggest that forests in Odisha state are likely to remain a sink of carbon during the 21st century.

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