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Effect of disturbance on biomass, production and carbon dynamics in moist tropical forest of eastern Nepal

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Abstract

Background: Forest biomass is helpful to assess its productivity and carbon (C) sequestration capacity. Several disturbance activities in tropical forests have reduced the biomass and net primary production (NPP) leading to climate change. Therefore, an accurate estimation of forest biomass and C cycling in context of disturbances is required for implementing REDD (Reducing Emissions from Deforestation and Forest Degradation) policy.

Methods: Biomass and NPP of trees and shrubs were estimated by using allometric equations while herbaceous biomass was estimated by harvest method. Fine root biomass was determined from soil monolith. The C stock in vegetation was calculated by multiplying C concentration to dry weight.

Results: Total stand biomass (Mg·ha^{-1}) in undisturbed forest stand (US) was 960.4 while in disturbed forest stand (DS) it was 449.1. The biomass (Mg·ha^{-1}) of trees, shrubs and herbs in US was 948.0, 4.4 and 1.4, respectively, while in DS they were 438.4, 6.1 and 1.2, respectively. Total NPP (Mg·ha^{-1}·yr^{-1}) was 26.58 (equivalent to 12.26 Mg C·ha^{-1}·yr^{-1}) in US and 14.91 (6.88 Mg C·ha^{-1}·yr^{-1}) in DS. Total C input into soil through litter plus root turnover was 6.78 and 3.35 Mg·ha^{-1}·yr^{-1} in US and DS, respectively.

Conclusions: Several disturbance activities resulted in the significant loss in stand biomass (53 %), NPP (44 %), and C sequestration capacity of tropical forest in eastern Nepal. The net uptake of carbon by the vegetation is far greater than that returned to the soil by the turnover of fine root and litter. Therefore, both stands of present forest act as carbon accumulating systems. Moreover, disturbance reflects higher C emissions which can be reduced by better management.

Keywords: Tropical forest, Disturbance, Biomass, Production, Carbon cycling, Nepal

Background

Tropical forests play an important role in the global C cycle. They contain about 55 % of global forest C (Pan et al. 2011) and account for 34 % of terrestrial gross primary production (Beer et al. 2010). Carbon is stored in forests mainly in biomass and soils. The C dynamics of a forest reflects environmental conditions such as climate, soil, structure, nutrient availability and disturbance (Chave et al. 2001). Forest disturbances often lead to the changes in species composition, structure, stand biomass, productivity and C cycling. Therefore, a small disruption in tropical forests might result in a significant change in the global C cycle.

Biomass and production are important parameters for understanding the functioning of a forest ecosystem. Studies on biomass help to assess the effect of disturbances on productivity, C dynamics, nutrient cycling and stability of forest stands. Primary production is usually regulated by the availability of nutrients. Decomposed fine roots and aboveground litter are the sources of nutrients in the soil. The contribution of fine roots in the C and nutrients input to soil is equivalent or even higher to that from leaf litter in tropical moist forests (Roderstein et al. 2005).

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Precise quantification of forest biomass, production, and C stock demands the careful estimation of both the aboveground and belowground aspects. Despite this requirement, most of the past studies in tropical forests are found to be limited to analyzing the aboveground systems (Chave et al. 2008; Djomo et al. 2011; Malhi et al. 2011; Doughty et al. 2013; Ngo et al. 2013; Girardin et al. 2014; Malhi et al. 2014) and only a few studies concern to the belowground aspects (Ibrahima et al. 2010; Powers and Perez-Aviles 2013; Noguchi et al. 2014).

In Nepal, only few studies have been conducted regarding the biomass, production, and C sequestration in tropical forests (Mandal 1999; Baral et al. 2009). More information is required to understand the structure and functioning of the forests. Present study was designed in tropical forest of eastern Nepal with the following specific objectives: a) to estimate the biomass and production of herb, shrub and tree species; b) to find out the effect of disturbance on biomass, production and C dynamics.

Methods

Study area

The study was conducted in a Sal (*Shorea robusta*) dominated moist tropical forest of Sunsari District, eastern Nepal (latitude 26°41'N to 26°50'N and longitude 87°09'E to 87°21'E), within the altitude range of 220 to 370 m above msl (Fig. 1). The forest lies in the catchment area of Koshi River, one of the largest rivers in Nepal. The total area occupied by the forest is 11394 ha.

The central part (core area) of the forest is relatively undisturbed, while the peripheral part is affected by disturbance activities as removal of timber, livestock grazing, fuel-wood and litter collection, tree lopping, removal of poles for house-hold constructions and forest fires. These disturbances have caused deforestation, forest fragmentation and degradation and subsequent invasion of exotic species like *Mikania micrantha*, *Lantana camara*, and *Chromolaena odorata*, which adversely affect the native plant diversity in the forest.

The climate is tropical and monsoon type with three distinct seasons: dry and warm summer (March to May), wet and warm rainy (June to October), and dry and cool winter (November to February). The mean monthly minimum and maximum air temperature during 2005–2014 ranged from 10.9 °C to 25.3 °C and 22.6 °C to 33.2 °C, respectively. The average annual rainfall for the period was 1998.6 mm (Fig. 2). Relative humidity was higher in rainy season with highest value in August (92 %).

The forest is bordered by the *Siwalik* hill in the north and the Gangetic alluvial plains in the south. The area has been formed from soft erodible sediments of the *Siwaliks* and is characterized by the presence of boulder beds mixed with sand, silt, clay imparting a porous nature. The soil mainly consists of deep alfisols.

The forest tree layer is dominated by Sal. Other main associates are *Haldina cordifolia*, *Lagerstroemia parviflora*, and *Terminalia alata*. *Clerodendron viscosum* and *Murraya koenigii* are some of the main shrub species while *Chromolaena odorata* and *Achyranthes aspera* are dominant herbs.

Plant biomass estimation

The forest was divided into 2 parts: i) the relatively undisturbed core area (treated as undisturbed stand; US), and ii) the disturbed peripheral area (treated as disturbed stand; DS). Because of the following characters the core area was considered as US: canopy area ranged between 153.8 and 226.9 m^2, crown cover ranged from 70–80 %, density of the tree was 466.4 individuals·ha^{-1} and tree stumps were absent. The peripheral part of the forest is disturbed because of following characters: canopy area ranged between 28.3 and 77.5 m^2, crown cover ranged from 30–40 %, tree density was 234.3 individuals·ha^{-1} and tree stump density was 70 stumps·ha^{-1}.

The tree biomass contained within US was estimated using 35 randomly established sample plots of 20 m × 20 m size determined by species-area curve method. Same size was applied for DS as well. For the estimation of shrub and herb biomass nested quadrats of 5 m × 5 m and 1 m × 1 m were used, respectively. Girths of all the trees (>10 cm gbh) at breast height (1.37 cm above the soil) and of shrubs (10 cm above the ground level) present in each of the sample plots were measured. Density (individual per hectare) and basal area (girth^2·(4π)$^{-1}$) of the trees within plots were determined. Biomass of trees was estimated by using girth:biomass allometric equations (Singh and Singh 1992; Mandal 1999). For estimating coarse root biomass, root:shoot ratio of 0.21 proposed for lowland tropical forests was used (Malhi et al. 2009; Malhi et al. 2014).

The aboveground herbaceous biomass present in the sampling plots was harvested twice, in summer (May 2012) and at the end of rainy season (September 2012). Summer and rainy season values were averaged to obtain annual mean herbaceous biomass.

Fine roots (<5 mm diameter) were collected from seventy randomly established sample plots, thirty five each in US and DS. Fine root biomass (FRB) was determined from soil monolith (10 cm × 10 cm × 30 cm), divided into two depth ranges (upper: 0–15 cm and lower: 15–30 cm) at each sample plot in summer (May 2011), rainy (September 2011) and
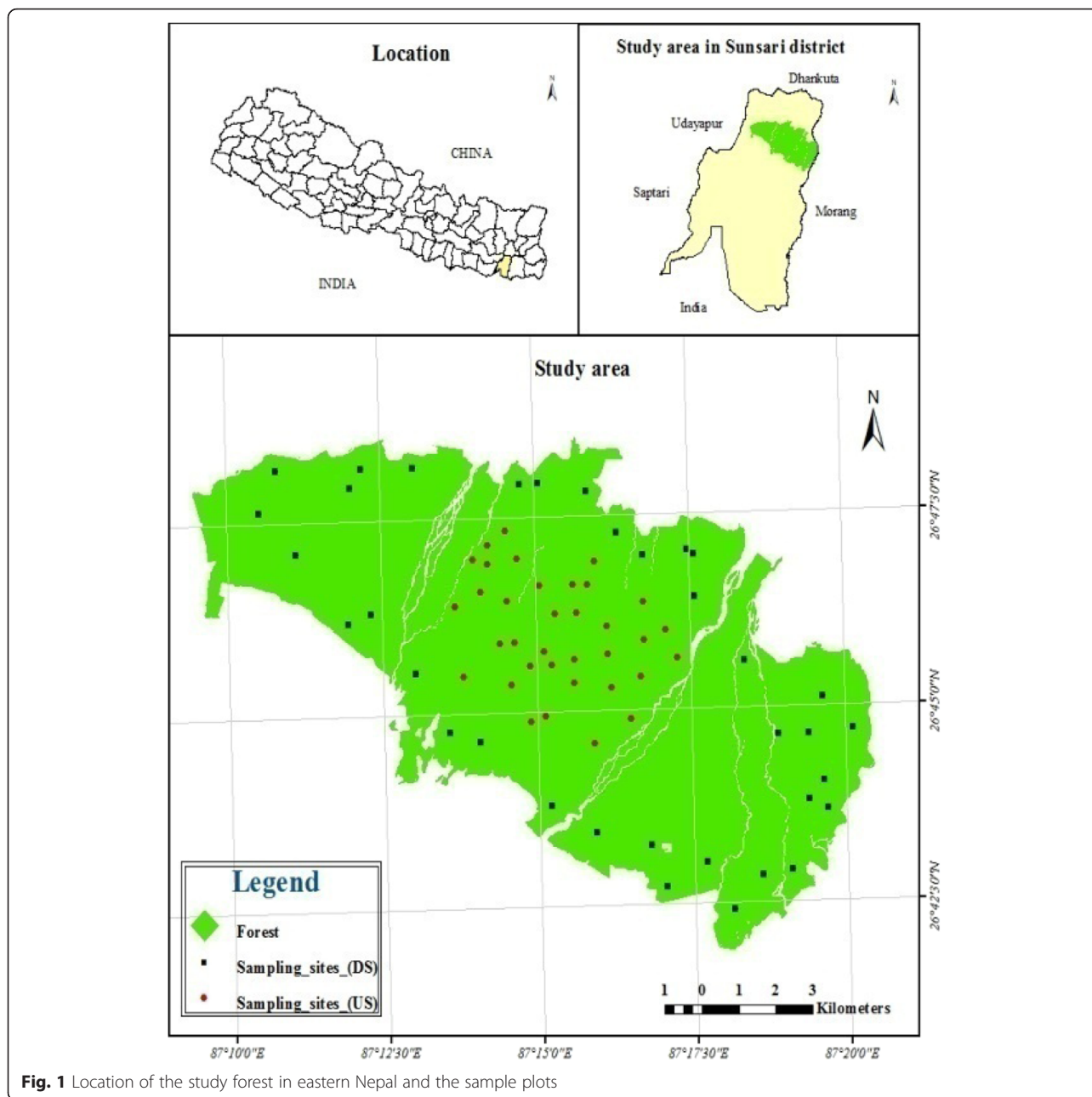
Fig. 1 Location of the study forest in eastern Nepal and the sample plots

winter (January 2012) seasons. Summer, rainy and winter season values were averaged to obtain annual mean FRB.
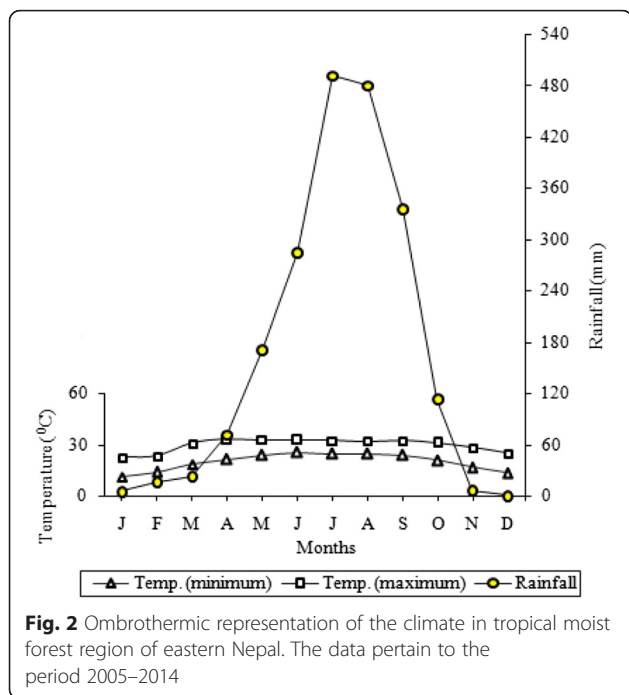
Litterfall and litter mass

For the estimation of litterfall one litter trap (1 m × 1 m) was fixed on the forest floor at each of the seventy sampling plots. Litterfall was collected at monthly intervals from April 2011 to March 2012 and categorized into leaf and non-leaf components. Litter mass accumulated at each sampling plot was collected once every season from one 1 m × 1 m plot.

The turnover rate of litter was calculated according to Jenny et al. (1949).

Net production

Using the allometric equations, the aboveground biomass (AGB) of different components of marked trees/shrubs in permanent sampling plots was computed for 2011 (B_1) and 2012 (B_2) from respective girth measurements. The net changes in biomass ($\Delta B = B_2 - B_1$) of components yielded annual biomass increments which were summed to get the net AGB accretion in the trees/shrubs. Aboveground herbaceous net production was estimated as the

Fig. 2 Ombrothermic representation of the climate in tropical moist forest region of eastern Nepal. The data pertain to the period 2005–2014

differences between maximum and minimum biomass values through the year.

The annual leaf fall was added to the foliage biomass accumulation to represent leaf production, and wood and miscellaneous litterfall values were added to the biomass accumulation in twigs (Singh et al. 1994). Coarse root production was estimated as a fraction of stem production (Malhi et al. 2009; Malhi et al. 2014). Fine root production (FRP) was estimated as the differences between maximum (rainy season values) and minimum (summer season values) biomass values. The fine root turnover was calculated as a ratio of its production and annual mean biomass (Srivastava et al. 1986).

Carbon estimation in vegetation and litter
Samples of different tree, shrub and herb (aboveground) components of all species were collected from each sampling plot. The litter (leaf and non-leaf) and fine root (< 2 and 2–5 mm diameter) samples were also collected. All the samples were oven dried at 80 °C to constant weight, powdered and used separately for C analyses.

Carbon present in plant materials was estimated by ash content method. Carbon concentrations were assumed to be approximately 50 % of ash free weight (McBrayer and Cromack 1980). In this method oven dried plant components (stem, branch, root, leaf, and litter) were burnt separately in electric furnace at 400 °C. Ash content (inorganic elements in the form of oxides) left after burning was weighed and

carbon concentration was calculated by using the following equation:

$$\% \, Carbon = (Initial \, weight - Ash \, weight) \times 100/2 \quad (1)$$

The C stock in vegetation was calculated by multiplying C concentration (a conversion factor) to dry weight. A conversion factor of 0.470 was used to convert aboveground and coarse root biomass to C. To obtain C stock in fine roots a conversion factor of 0.430 and 0.455 was used for < 2 and 2–5 mm size class, respectively. The conversion factors of 0.453 and 0.468 were used for leaf and non-leaf litter, respectively.

Soil sampling and carbon estimation
Soil samples were collected from 70 randomly selected pots (35 each in US and DS). Soil was collected from three pits (10 cm × 10 cm × 30 cm each) from each plot. The soils of three pits were mixed and pooled as one replicate (Singh et al. 2001). Bulk density (BD) was determined by using a metallic tube while soil organic carbon (SOC) by dichromate oxidation method (Kalembasa and Jenkinson 1973). Carbon content in soil (Mg C·ha^{-1} soil) was calculated using the formula:

$$C = SOC \times soil \, depth \times BD \quad (2)$$

where SOC is soil organic carbon in % and BD is bulk density (g·cm^{-3}).

Statistical analysis
Statistical tests were carried out in MS excel 2007 and SPSS (IBM Statistics, ver. 20) packages. All the data were normally distributed except that of basal area of trees which were log transformed before analysis. Pearson's correlation coefficients were obtained between normal and linear data of biomass, net production, stand density and basal area of trees. Students T-test was performed to compare the mean biomass and production of trees between US and DS.

Results
Plant biomass
The biomass and C stocks of trees, shrubs, herbs and fine roots are summarized in Tables 1 and 2. The estimated total biomass for the US was 960.4 Mg·ha^{-1} (equivalent to 452.06 Mg C·ha^{-1}), while for DS it was 449.1 Mg·ha^{-1} (equivalent to 211.33 Mg C·ha^{-1}).

The total biomass (Mg·ha^{-1}) of the tree layer in US and DS was found to be 948.0 and 438.4, respectively. The tree biomass in the US and DS was significantly different ($P < 0.001$ at 95 % confidence level). Of the total tree biomass, 83 % was aboveground and 17 % belowground

Table 1 Oven-dried stand biomass (Mg·ha^{-1}) and carbon stock (Mg C·ha^{-1}) in moist tropical forest of eastern Nepal

Components		Undisturbed stand		Disturbed stand	
		Biomass	Carbon stock	Biomass	Carbon stock
Trees	Bole	610.4 ± 20.0	287.5	281.5 ± 15.8	132.59
	Branch	119.4 ± 3.2	56.23	56.8 ± 3.1	26.75
	Twig	32.9 ± 1.6	15.59	14.5 ± 0.9	6.87
	Leaf	20.8 ± 0.8	9.67	9.5 ± 0.5	4.42
	Coarse root	164.5 ± 12.0	77.48	76.1 ± 11.0	35.84
	Total	948.0 ± 108.8	446.47	438.4 ± 50.1	206.47
Shrubs	Stem	2.0 ± 0.2	0.94	3.00 ± 0.4	1.41
	Leaf	1.0 ± 0.1	0.46	1.14 ± 0.1	0.52
	Root	1.4 ± 0.1	0.66	1.92 ± 0.2	0.90
	Total	4.4 ± 0.3	2.06	6.1 ± 0.5	2.83
Herbs[a]		1.4 ± 0.1	0.61	1.2 ± 0.1	0.53
Stand fine root		6.6 ± 0.1	2.92	3.4 ± 0.2	1.50
Total, Vegetation		960.4 ± 73.1	452.06	449.1 ± 33.6	211.33

[a]Aboveground parts

(excluding fine root) in both the stands. The maximum contribution to tree AGB was made by bole in both stands (64 % each) and minimum by foliage (2 % each in both stands).

The shrub biomass (Mg·ha^{-1}) showed increasing trend from 4.4 at US to 6.1 at DS. Contribution of shrub biomass to the total stand biomass was higher in DS (1.4 %) than US (0.5 %). The aboveground herbaceous biomass contributed 0.1 % in US and 0.3 % in DS. The fine roots shared 0.7–0.8 % to total stand biomass. The annual FRB was lower in DS by 49.5 %.

Litterfall

The total annual litterfall (Mg·ha^{-1}·yr^{-1}) was 11.8 in US and 5.4 in DS. Leaves accounted for 69 % (US) to 76 % (DS) of total litterfall while non-leaf litter formed the rest. The total litter mass (Mg·ha^{-1}) comprised 6.7 in US and 3.6 in DS. The turnover rate (per yr) of the total litter ranged from 0.79 in DS to 0.83 in US.

Net production

The total NPP (Mg·ha^{-1}·yr^{-1}) of the forest was 26.6 (equivalent to an annual C sequestration of 12.26 Mg C·ha^{-1}·yr^{-1}) in US and 14.9 (i.e. 6.88 Mg C·ha^{-1}·yr^{-1}) in DS (Table 3). Among the different life forms: tree, shrub, and herb comprised 72 %, 2 %, and 6 % of NPP in US and 67 %, 5 %, and 9 % in DS, respectively; while rest 20 % NPP in US and 19 % in DS were contributed by stand fine root.

The contribution in NPP by different components of trees was in the order leaf > bole > twig > coarse root > branch, in both stands (Table 4). The most prominent C sink was found to be leaf that accounted for 42–43 % of the total NPP. For shrub, maximum contribution to NPP was made by stem in both stands and minimum by foliage. The NPP of herbs (aboveground) ranged between 1.3 and 1.7 Mg·ha^{-1}·yr^{-1} in DS and US, respectively (Table 3).

Total aboveground NPP (Mg·ha^{-1}·yr^{-1}) combining tree, shrub and herb were 19.93 in US and 10.97 in DS. In belowground parts, percentage allocation of NPP was up to 25 % of total NPP (26.58 Mg·ha^{-1}·yr^{-1}) in US and 26 % (3.94 Mg·ha^{-1}·yr^{-1}) in DS (Table 5). Of this, both tree and shrub's coarse root contributed about 21 and 26 % to total belowground NPP in US and DS, respectively; whereas fine root comprised nearly 79 % of belowground NPP in US and 74 % in DS.

Table 2 Carbon stock (Mg C·ha^{-1}) estimates for undisturbed and disturbed stands of moist tropical forest of eastern Nepal

Component	Undisturbed stand		Disturbed stand	
	Carbon stocks	% of total	Carbon stocks	% of total
Aboveground biomass	371.0	68.7	173.1	64.0
Coarse roots	78.1	14.5	36.7	13.6
Fine roots	2.9	0.5	1.5	0.5
Soil (to 30 cm depth)	88.1	16.3	59.3	21.9
Total	540.2	100	270.6	100

Table 3 Net primary production (NPP; Mg·ha⁻¹·yr⁻¹) and carbon allocation (Mg C·ha⁻¹·yr⁻¹) in different components of vegetation in moist tropical forest of eastern Nepal

Components		Undisturbed stand		Disturbed stand	
		NPP	Carbon allocation	NPP	Carbon allocation
Trees	Bole	4.78 ± 0.25	2.25	2.96 ± 0.16	1.39
	Branch	0.91 ± 0.05	0.43	0.57 ± 0.03	0.27
	Twig	3.93 ± 0.02	1.86	1.45 ± 0.01	0.69
	Leaf	8.24 ± 0.01	3.83	4.19 ± 0.01	1.95
	Coarse root	1.27 ± 0.02	0.60	0.79 ± 0.06	0.37
	Total	19.13 ± 1.21	8.97	9.96 ± 0.75	4.67
Shrubs	Stem	0.30 ± 0.03	0.14	0.42 ± 0.04	0.20
	Leaf	0.07 ± 0.04	0.03	0.08 ± 0.01	0.04
	Root	0.18 ± 0.02	0.08	0.25 ± 0.02	0.12
	Total	0.55 ± 0.07	0.25	0.75 ± 0.10	0.36
Herbs[a]		1.70 ± 0.12	0.74	1.30 ± 0.09	0.57
Stand fine root		5.20 ± 0.21	2.30	2.90 ± 0.16	1.28
Total, Vegetation		26.58 ± 0.87	12.26	14.91 ± 0.44	6.88
[b]BAR		36		30	

[a]Aboveground parts
[b]BAR: Biomass accumulation ratio (biomass/annual net production)

Considering both depths, average turnover rate (per yr) of smaller fine roots (0–2 mm diameter) was 0.75 in US and 0.86 in DS, whereas it was 0.74 and 0.76 for larger size class (2–5 mm) in US and DS, respectively. The biomass accumulation ratio (biomass/net production) decreased to 30 due to the consequences of forest disturbance in DS, while this value was higher (36) in US. Net production of trees was significantly higher in US than DS ($P < 0.001$). Positive correlations were found between stand density, basal area, biomass and NPP of trees in both stands (Table 5).

Table 4 Net production (Mg·ha⁻¹·yr⁻¹) of trees and shrubs and their distribution (%) in different components in moist tropical forest of eastern Nepal

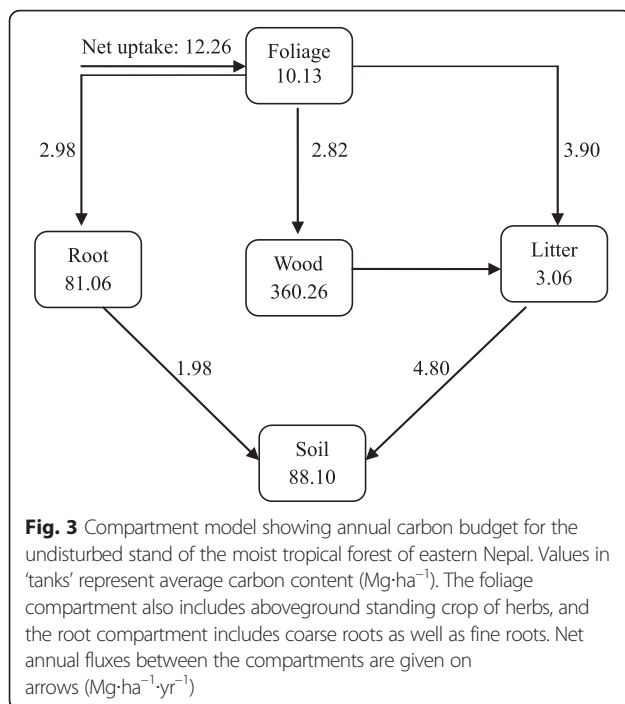| Components	Forest stands	
	Undisturbed	Disturbed
Trees	19.13 ± 1.21	9.96 ± 0.75
Bole (%)	25	30
Branch (%)	5	6
Twig (%)	20	14
Leaf (%)	43	42
Coarse root (%)	7	8
Shrubs	0.55 ± 0.07	0.75 ± 0.10
Stem (%)	54	56
Leaf (%)	13	11
Root (%)	33	33

Carbon budget and flux

The dry matter values for standing crops, net production, litterfall etc. of both undisturbed and disturbed stands were converted to C (Figs. 3 and 4). Aboveground C storage in both stands was 82 % of the total C in vegetation and 64–69 % of that stored in stand (vegetation plus soil). The forest received a C input through NPP of 12.26 Mg·ha⁻¹·yr⁻¹ in US and 6.88 Mg·ha⁻¹·yr⁻¹ in DS. Of this, 69 % was associated with aboveground and 31 % with root NPP in US while in DS, contributions from aboveground and root parts to total NPP was 67 and 33 %, respectively.

Wood (bole plus branch) and roots accounted for 47 % (in US) to 53 % (in DS) of the total C input, the remaining 53 % in US and 47 % in DS being utilized for
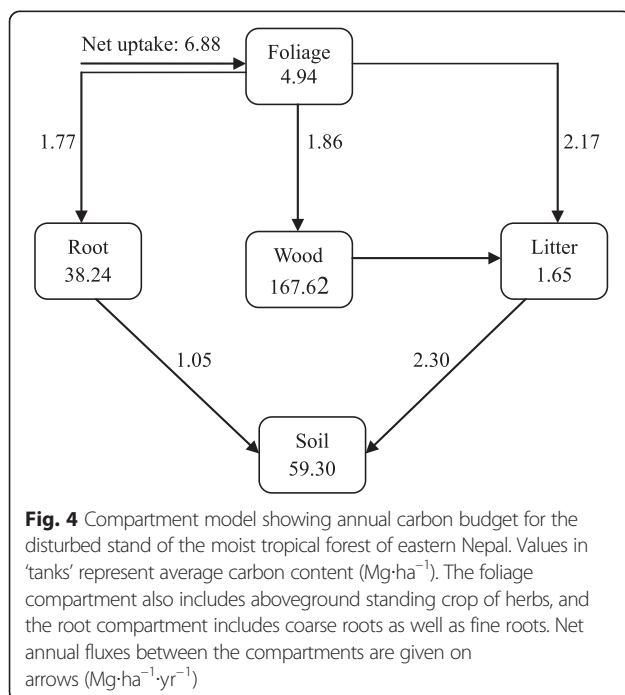
Table 5 Pearson's correlations between stand density, basal area, biomass and net production of trees in undisturbed and disturbed stands of moist tropical forest in eastern Nepal

	Density	Basal area	Biomass
Undisturbed stand			
Basal area	0.293		
Biomass	0.251	0.902[b]	
Net production	0.725[b]	0.210	0.279
Disturbed stand			
Basal area	0.116		
Biomass	0.221	0.926[b]	
Net production	0.788[b]	0.347[a]	0.525[b]

[b]Correlation is significant at the 0.01 level (2-tailed) and [a]at the 0.05 level (2-tailed)

Fig. 3 Compartment model showing annual carbon budget for the undisturbed stand of the moist tropical forest of eastern Nepal. Values in 'tanks' represent average carbon content (Mg·ha^{-1}). The foliage compartment also includes aboveground standing crop of herbs, and the root compartment includes coarse roots as well as fine roots. Net annual fluxes between the compartments are given on arrows (Mg·ha^{-1}·yr^{-1})

the extension of the photosynthetic parts (tree and shrub foliage plus herbaceous shoots). The input from the foliage compartment to the litter compartment was 3.90 Mg·ha^{-1}·yr^{-1} (equivalent to 100 % of herbaceous aboveground production plus 86 % of foliage production) in US while it was 2.17 Mg·ha^{-1}·yr^{-1} for DS. About 14 % (0.51 Mg·ha^{-1}·yr^{-1} in US and 0.26 Mg·ha^{-1}·yr^{-1} in DS) of foliage production did not find its way into leaf litterfall.

Fig. 4 Compartment model showing annual carbon budget for the disturbed stand of the moist tropical forest of eastern Nepal. Values in 'tanks' represent average carbon content (Mg·ha^{-1}). The foliage compartment also includes aboveground standing crop of herbs, and the root compartment includes coarse roots as well as fine roots. Net annual fluxes between the compartments are given on arrows (Mg·ha^{-1}·yr^{-1})

Carbon addition to the soil through the turnover of roots and aboveground litter amounted to 1.98 and 4.80 Mg·ha^{-1}·yr^{-1}, respectively in US (fine root and litter turnover were 86 and 83 % per yr, respectively). Similarly, C input due to the turnover of roots and aboveground litter was 1.05 and 2.30 Mg·ha^{-1}·yr^{-1}, respectively in DS (fine root and litter turnover were 82 and 79 % per yr, respectively). Evidently, contribution of belowground plant parts to soil C is substantial, representing 29 and 32 % of the total input in US and DS, respectively.

Discussion

Biomass and production

The average biomass of the vegetation in both US and DS was 704.8 Mg·ha^{-1} (331.7 Mg C·ha^{-1}). More than double biomass in US as compared to DS may be related to the presence of more trees of larger girth classes. The lower biomass in DS may be the result of lower density of trees (234 individuals·ha^{-1}) compared to US (466 individuals·ha^{-1}). It may also be associated with disturbance activities like tree felling and removing for timber, firewood collection, lopping, grazing, and selective logging.

Biomass allocated to shrub was higher in DS than US. It may be the result of their ability to utilize the space and resource created by disturbances. The higher biomass of herbs in US as compared to DS may be due to the nutrient rich soil at this stand (Gautam and Mandal 2013). The different causes are put forward by different workers regarding the accumulation of biomass in the forest. Mean annual precipitation explains 55 % of the variation in biomass in seasonally dry tropical forests (Becknell et al. 2012). The available nutrients, soil, land use history, species composition and stand age are also responsible for the remaining variations (Powers et al. 2009).

Most of the C stock in the forest was associated with AGB (64–69 %). Belowground biomass and soil up to the depth of 30 cm contained 31 to 36 % C stock. Past study also found 33 % C in top soil of 1 m in primary tropical forest of Singapore (Ngo et al. 2013). Globally, tropical forests store about 50 % C in AGB and next 50 % within 1 m soil (Dixon et al. 1994). The contribution of these pools to the total C stocks varies among the sites. For example, an African moist tropical forest had more than three times as much C in AGB as in soil to 1 m depth (Djomo et al. 2011), while a Peruvian montane forest had twice as much C in soil as in AGB (Gibbon et al. 2010). Two Asian forests, a tropical seasonal forest in China (Lü et al. 2010) and a lowland dipterocarp forest in Malaysia (Saner et al. 2012) store twice as much C in biomass as in soil. The contribution of leaf fall to total litterfall in the present study (69 % at US and 76 % at DS) is in the range of past studies in tropical forests (72–74 %) (Girardin et al. 2014; Malhi et al. 2014).

The data obtained for NPP are comparable with the different tropical forests of world (Table 6). Although having higher biomass, the NPP of present forest is relatively low indicating its maturity. Generally, in old growth tropical forests the NPP remains either stationary or decreases with age. The higher NPP of some old tropical forests may be linked to forest dynamics. The more dynamic forests favor faster growing trees and species with lower biomass and maintenance costs (Malhi et al. 2009).

Aboveground NPP of US (8.54 Mg C·ha^{-1}·yr^{-1}, excluding herbs) is comparable with the tropical forests of world while quite low than the eastern Amazonian forest (Doughty et al. 2013). Moreover, aboveground NPP of DS (4.54 Mg C·ha^{-1}·yr^{-1}, excluding herb) is near to paleotropical forests, and mean of the world tropical forests. As far as the belowground NPP is concerned (1.77–2.98 Mg C·ha^{-1}·yr^{-1}), it is comparable to the Amazonian tropical forest (Table 6).

Disturbance affects the NPP either by increasing resource availability or through the changes in functional properties of community. The disturbance results in canopy opening, which increases availability of light, favor new leaf production, and finally above-ground allocation increases (Aragão et al. 2009). But in the present study, percentage allocation to aboveground parts was almost same in both US and DS. It may be the result of severe lopping activities in DS, which is also indicated by less percentage of NPP allocation to twig and leaf, and higher percentage allocation to bole and branch in DS. Relatively higher percentage of NPP in coarse root of DS indicated higher allocation to root to collect more water and nutrients from nutrient deficient soil.

Among different components of trees, leaf accounted highest percentage (43 % in US and 42 % in DS) of tree NPP. It was almost similar to the earlier findings for tropical forests (Hertel et al. 2009; Doughty et al. 2013). A global dataset of NPP allocation in tropical forests reported 34 % in canopy, 39 % in wood, and 27 % in fine roots (Malhi et al. 2011). Present data of US, excluding herb NPP, also showed almost same pattern of allocation (33 % canopy, 46 % woody tissue including coarse root, and 21 % fine roots).

Higher allocation of NPP in shrubs of DS as compared to that of US may be due to open canopy created as a result of logging and lopping of trees. The higher NPP of herbs in US might be associated with higher moisture and nutrients due to accumulation of more litter on the soil. Fine root, although sharing a very small percentage to total plant biomass, is one of the major belowground components of the NPP. In present study, FRB shared less than 1 % to total biomass but contributed 19–20 % to total NPP. The estimated FRP in this study was within the ranges of 1.1–6.2 Mg·ha^{-1}·yr^{-1} for global tropical forests (Vogt et al. 1986).

Carbon budget and flux

Aboveground C storage in both stands was 82 % of the total stored in vegetation and 64–69 % of that stored in the stand (vegetation plus soil). These values compare with the aboveground storage of 83 % vegetation C and 51 % stand C in a dry tropical forest in India (Singh and Singh 1991). As in other tropical forests, relatively higher contribution of aboveground parts to the stand C in present case may be due to the presence of large sized trees with wide canopy.

The contribution of aboveground (74–75 %) and root (25–26 %) parts to stand NPP in both forest stands is comparable to 72 % NPP for aboveground parts (Singh and Singh 1991). The higher contribution of wood parts to the total C input as compared to foliage in DS may be due to the lopping of branches and twigs. On the other hand, closed canopy of trees in US accounted for higher input of foliage C compared to wood.

The transfer of C from foliage compartment to the litter compartment involved 100 % of herbaceous aboveground production plus 86 % of foliage production while the remaining amount, i.e., about 14 % of foliage production did not find its way into leaf litterfall. It happens due to the losses during senescence (Singh and Singh 1991).

Table 6 Net primary production (NPP) of different forests of the World

Locality and forest types	NPP (Mg C·ha^{-1}·yr^{-1})			References
	Aboveground	Belowground	Total	
Amazonia	–	–	10.0–14.4	(Malhi et al. 2009)
Peru (W. Amazonia)	–	–	14.2–15.1	(Malhi et al. 2014)
Global (Old tropical)	–	–	3.1–21.7	(Chave et al. 2001)
Central French Guiana (Lowland tropical rain)	8.81	–	–	(Chave et al. 2008)
Africa (Tropical)	–	–	11.51	(Bombelli et al. 2009)
Nepal (Moist tropical Plateau Sal)	14.89	7.21	22.1 ± 1.4	(Mandal 1999)
Nepal (Moist tropical)	10.97–19.93	3.94–6.65	14.91–26.58	Present study

Litterfall and FRB are important vectors of nutrient recycling in forest ecosystems. Their turnover is usually determined by species, age groups, canopy cover, weather conditions and biotic factors. Total C input into soil through litter plus root turnover was 6.78 and 3.35 Mg$\cdot$ha$^{-1}\cdot$yr^{-1} in US and DS, respectively, suggesting substantial retention of C in the vegetation over in annual cycle (45 % in US and 51 % in DS). It indicates that the present forest is C-accumulating system, acting as a significant global C sink, as other wet tropical forests (Pan et al. 2011).

Conclusions

The present study indicated that various types of anthropogenic disturbances have altered the structure and functioning of the economically important Sal-dominated forest. Although in having higher biomass, the NPP of present forest is relatively low indicating its maturity. Several disturbance activities like lopping, fodder collection, litter removal, grazing etc. result in the significant loss in stand biomass (53 %) and net production (44 %). Due to forest disturbance C stock and C sequestration capacity are reduced which reflects the higher C emissions. From the management point of view, better policy to reduce the C emission through vegetation should be formulated as per the objective of REDD$^+$. In spite of this, both stands of this forest appear to act as C-accumulating system, an important global C sink.

Abbreviations
AGB: aboveground biomass; DS: disturbed forest stand; NPP: net primary production; US: undisturbed forest stand.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
TP carried out field and laboratory works, analyzed data, designed and drafted the manuscript. TN designed and supervised the research. Both authors read and approved the final manuscript.

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