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RESEARCH PAPER

Effect of anthropogenic disturbance on biomass allocation to different above- and below-ground vegetation components of a dry tropical forest in India

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Abstract

Biotic and anthropogenic disturbances are mediating changes in species diversity and vegetation composition in different regions of the world. Such changes may affect plant biomass allocation patterns in different tree components and vegetation types. To assess the impact of anthropogenic disturbances such as grazing, lopping, harvesting of non-wood forest products, fuel wood and fodder collections on biomass allocation to different components of the vegetation, two study sites i.e., one undisturbed site and the other a disturbed site located in the Barnawapara Wildlife Sanctuary, Chhattisgarh were selected. Biomass allocation was measured by placing ten (10 m × 10 m) quadrats randomly, at both the forest sites (i.e., disturbed and undisturbed). Based on the regression equations relating tree circumference to dry weight of components (viz., bole, branch, leaf, and root), biomass of different vegetation components (i.e., above- and below-ground) was measured. Total biomass (above- and below-ground, including herbaceous shoots and litter mass) was significantly ($P < 0.05$) higher on the undisturbed site (360.38 t ha^{-1}) compared to the disturbed site (113.99 t ha^{-1}). Among different above-ground components, most of the biomass was allocated to branches followed by bole and leaf. Above-ground biomass ranged between 76.47 and 270.87 t ha^{-1} with higher value at undisturbed forest site and the lower at the disturbed forest site. The below-ground biomass varied between 37.52 and 89.51 t ha^{-1}, and like above-ground biomass it was also higher at the undisturbed forest site and lower at the disturbed forest site. A higher (~8%) biomass allocation to below-ground component was observed at the disturbed site, compared to the undisturbed site. Moreover, the proportion of biomass in the herb layer was higher at the disturbed site compared to the undisturbed site. Based on the results of present study, it can be concluded that under the disturbed conditions plants allocate major portion of the biomass to the below-ground and herbaceous components in the tropical dry deciduous ecosystems.

Keywords Barnawapara wildlife sanctuary · Carbon storage · Disturbance · Foliage · Herbaceous layer · Litter mass · Tropical vegetation

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Introduction

As compared to other terrestrial ecosystems, forests sequester more C and are important natural ‘brake’ on global climate change (Gibbs et al. 2007). In the recent years, quantification of plant biomass and the carbon (C)-fixation potential of forest ecosystems are getting wider attention of the scientific community (Usuga et al. 2010). Role played by tropical forests in global C cycle is important (Singh 2010; Raj and Jhariya 2021a). In the tropical regions due to scarcity of reliable measurements on tree biomass and its variation across landscapes and forest types, live tree biomass pool is an important source of uncertainty in the C balance (Alves et al. 2010). However, the tropical forests are experiencing a high level of natural and/or anthropogenic disturbance (Singh et al. 2022). Disturbance is a temporary change in environmental conditions that causes a marked change in an ecosystem’s structure and functioning (Chaturvedi et al. 2023). Undisturbed forest (UF) is the forest that has never been logged and has developed in accordance with natural disturbances and under natural processes. Whereas the direct human disturbances like grazing, lopping, harvesting of non-wood forest products, fuel wood and fodder collections are the drivers that lead to the development of disturbed forests/converted forest (Chaturvedi et al. 2023).

Knowledge on spatial and inter-annual variation in tree growth and forest productivity both are essential for evaluating potential forest management alternatives as well as forest carbon balances (Luo et al. 2005). Above-ground biomass is an important variable in the yearly and long-term changes in the global terrestrial C cycle and other earth system interactions. Built up in above-ground biomass is related to the recruitment and mortality of stems and the taking over of small and large stems into forest canopy (Marcelo et al. 2007). In addition, climate, soil structure, nutrient availability, disturbance, and tree diversity further decide the biomass accumulation in a forest (Allen et al. 2017). To understand C pool changes of the forest, quantification of biomass is necessary as the primary inventory data. However, litter production and decomposition play an important role on the regulation of nutrient cycling, soil fertility and primary productivity in the forest ecosystem (Swift et al. 1979; Patil et al. 2020). The herbaceous layer also acts as an indicator of environmental changes (Singh et al. 2017*)*. Thus, exploring the biomass allocation to different components (viz., above- and below-ground biomass, litter and herbaceous layers) of forest vegetation is important for assessing their respective roles in global C storage and climate change mitigation.

Forest Survey of India (FSI 2021) has reported 21.71% forest cover in India, of the total geographical area of the country. Habitat destruction, ecological contamination (pollution), over-exploitation and anthropogenic stresses are the major disturbing factors for different ecosystems (Goparaju et al. 2005). 38.2% of the total forest area in India is covered by dry tropical forest, which is mainly affected by cropping, consumption, overgrazing and clearing (Singh and Singh 1988; Chaturvedi et al. 2017). Among tropical forest ecosystems, tropical dry forests are especially threatened by moderately high population densities, rural extension and expanded human reliance for fuel wood, non-timber forest products, and grazing by livestock (Jha and Singh 1990; Singh et al. 2022). Although the forest department claims that forest under the control of different state forest departments is untouched and there is no biotic and anthropogenic pressure i.e. grazing, lopping, illicit felling, collection of fuel wood, etc., but the ground reality is entirely different. In real sense, the biotic and anthropogenic pressures are a regular phenomenon particularly in those forest area which are in the vicinity of human habitation management (Singh et al. 2022). It is observed that the forests in the outer periphery are highly disturbed and exposed to the anthropogenic disturbances which lead to the degradation of forest (Goparaju et al. 2005). On the other hand, the inner most parts of the forests remain intact and are least disturbed. Therefore, it is imperative to assess the biomass allocation behaviour of different species growing under different disturbance regimes.

Our study was aimed to quantify the effect of disturbance on biomass allocation to different vegetation components (viz., above- and below-ground parts of trees, litter and herbaceous layers) of a dry tropical forest in India. We hypothesized that the disturbance may lead to the allocation of biomass more towards the below-ground component of the vegetation. The objectives to achieve this hypothesis were to: (1) estimate the biomass allocation to different tree components such as branch, bole, leaves and roots, (2) estimate the biomass allocation to the ground cover such as litter and herb layer, and (3) to estimate the change in biomass allocation to different vegetation components (i.e., above- and below-ground) in response to the disturbance.

Material and methods

Study area

The study area is located between 20°47′00″ to 21°31′30″ N latitude and 82°00′ to 83°15′45″ E longitude in the Barnawapara Wildlife Sanctuary (BWS), Chhattisgarh, India, at 463 m above the mean sea level (Fig. 1). It is 17 km from Patewa, on the Mumbai-Bhawanipatna NH No. 06, that is on the periphery of Chhattisgarh. Study

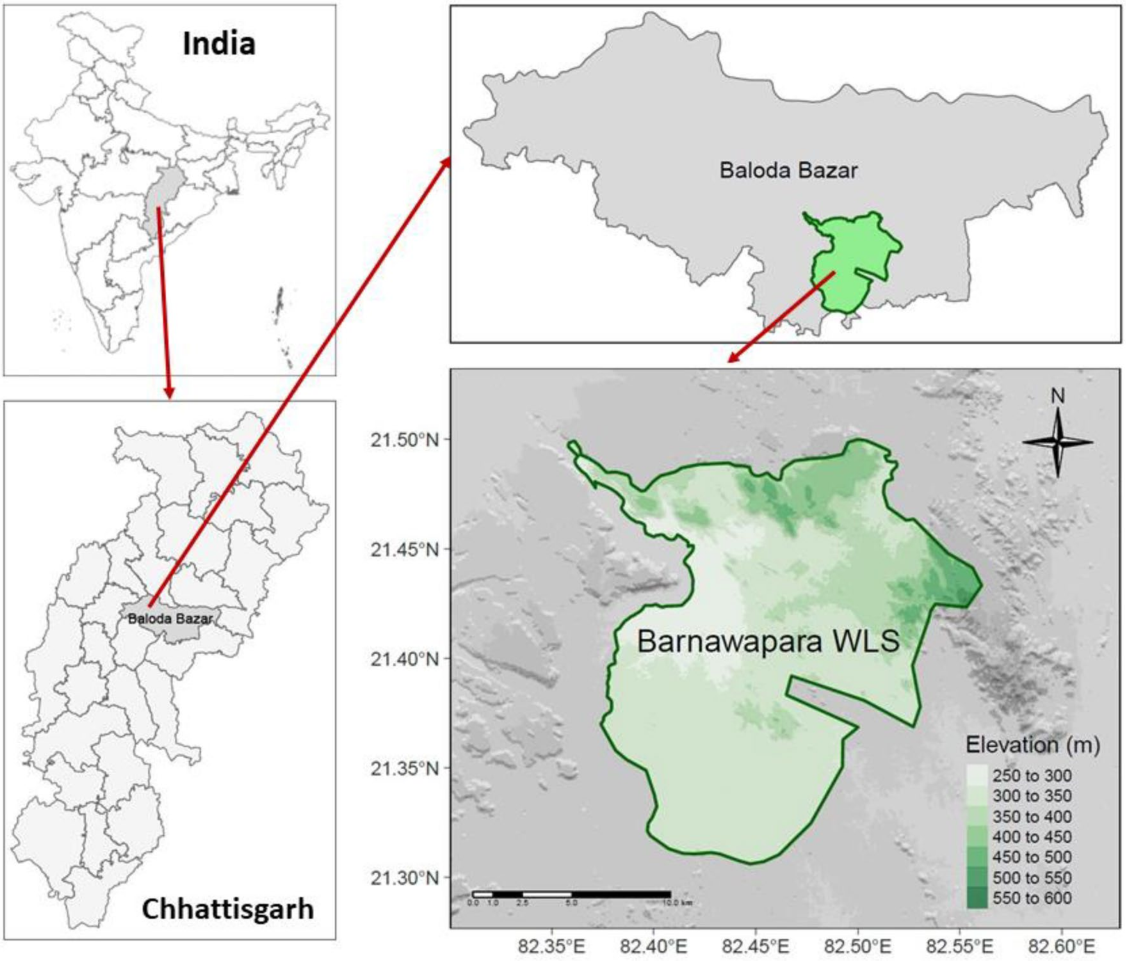

Fig. 1 Study area map of the Barnawapara Wildlife Sanctuary, Chhattisgarh, India. (Map is prepared in R Program, using *osmdata* package (Padgham et al. 2017))

sites were near the Nawapara forest village. The topography is undulating because of the presence of rock outcrops. The study area is surrounded with grasslands, agriculture lands, a dry deciduous forest and human habitations. Villages of the study area are named as forest villages and many of them are reachable via kachcha (un-mortared or unmetalled) roads, and that too only during the dry season (Thakrey et al. 2022).

The climate is dry tropical and is influenced by monsoon conditions. The year is divisible into three seasons, namely rainy (mid-June to September), winter (November to February) and summer (April to mid-June). October and March comprise transitional periods, respectively between rainy and winter, and between winter and summer seasons. The total annual rainfall is 1200–1350 mm, of this about 80% is received during rainy season (maximum in July). The number of rainy days in a year ranged between 90 and 100. The average annual maximum and minimum temperatures are, respectively 33.2 °C and 20.3 °C. Soil of the study area is sandy loam and comprises either Inceptisols, Vertisols or Alfisols (Thakrey et al. 2022).

Northern and Eastern sides of the region comprised of dense forests, whereas Teak plantations are common in the southern side. In western side, huge mixed and degraded forests occur with patches of bamboo plants. Champion and Seth (1968) have classified the forest of study area as Southern tropical dry deciduous Teak forests (5A/C1b), Northern tropical dry deciduous Sal forests (5B/C1c), Northern tropical mixed deciduous Sal forests (5B/C2) and Dry bamboo brakes (5/E9).

Site selection

Based on the repeated reconnaissance, two sites were identified namely, undisturbed and disturbed. The disturbed site was exposed to different biotic and anthropogenic pressures such as grazing, lopping, illicit felling, collection of fuel wood, etc. at regular intervals, and mostly located in the outer periphery of the forest ecosystem. The dominant vegetation at the disturbed site was *Terminalia tomentosa*, *Cleistanthus collinus*, *Buchnania lanzan*, *Diospyros melanoxylon* and *Ehretia laevis*. On the other hand, the inner most part of the forests remains intact and least disturbed, and was taken as undisturbed forest site in this study. The dominant vegetation at undisturbed site was *D. melanoxylon*, *Bixa orellana*, *C. collinus*, *Buahinia retusa* and *Shorea robusta* (Thakrey et al. 2022).

Incidences of disturbance were observed during the study period. A direct encounter with anthropogenic disturbance deals with the modes of human interference at the selected forest site that significantly affects the forest structure and functions. The villagers near the selected forest sites frequently visit the area to fulfil their daily requirements such as fodder for livestock, fuel and fire wood collection, etc. Many encounters with the livestock inside the forest. They are not only feeding on the herbaceous biomass but also consuming the seedlings of valuable species. Some villagers were involved in illicitly cutting the whole trees (e.g., *D. melanoxylon, S. robusta*, *Lannea coromandelica,* and *Madhuca latifolia*) at the disturbed forest site. The disturbance in the form of girdling and debarking leads to damage to the coppice shoots and saplings thereby forest regeneration gets affected (Thakrey et al. 2022).

Experimental design and sampling

A permanent plot of 100 m × 100 m (i.e., 1 ha) in area representing the overall vegetation was chosen and marked on each of the two sites (i.e., disturbed and undisturbed) for the detailed study. Ten quadrats, each of 100 square meters were placed randomly in disturbed as well as in non-disturbed forest sites, and the values obtained were averaged. Thus, there were 10 replicates. Girth of each trees at breast height i.e. 1.37 m (GBH) in each quadrat was measured and recorded. Shrubs were also measured at 10 cm above the ground.

For the quantification of tree biomass, regression equations developed earlier for dry deciduous forests by Singh and Misra (1979) were used. Computation method as described by Singh and Singh (1991) was used. In brief, average girth value for each species for a girth class was used in the regression equation to obtain an estimate of average biomass (by component) for that girth class, further these values were multiplied by the density of the tree or shrubs in respective girth class for each quadrat. The estimates were averaged across the number of quadrats to obtain the mean estimate for the sites. The aboveground herbaceous biomass was measured in 0.5 m × 0.5 m quadrats, oven dried and weighed. Litter biomass was also measured in 50 cm × 50 cm quadrats, oven dried and recorded.

The correlation between a tree girth and dry weight was determined by the regression equation:

$$\text{Log Y} = \text{a} + \text{b} \log \text{X}$$

where, Y = dry weight (kg) of the component (bole, branch, leaf or root), X = girth (cm) at 1.37 m height, and ‘a’ and ‘b’ are regression constants.

Data analysis

Data were subjected to independent t-test using SPSS (ver. 16) package for evaluating the impact of disturbance on forest biomass in different vegetation components. Values were considered significant if $P < 0.05$.

Results

Biomass allocation in different tree components at disturbed and undisturbed sites

The biomass apportionment in tree components (viz. bole and foliage) varied significantly ($P < 0.05$) whereas non-significant observations were observed for branch and root components at disturbed and undisturbed sites (Fig. 2). Biomass distribution to different plant parts (i.e., bole, branch, foliage (leaves) and coarse roots) relative to the total biomass was found 28.63, 35.86, 2.92 and 33.59%, respectively, at disturbed sites, whereas 26.26, 46.39, 2.26 and 25.08%, respectively, at undisturbed sites (Fig. 2). The bole biomass at disturbed and undisturbed forest sites ranged between 30.86 and 93.73 t ha^{-1} (Fig. 2). The bole biomass was 203% higher at undisturbed forest site as compared to the disturbed forest site. Branch biomass also varied between undisturbed and disturbed forest sites, and ranged from 40.06–165.56 t ha^{-1}. It was found 312% higher at undisturbed forest site as compared to the disturbed forest site. However, the differences between disturbed and undisturbed sites were not statistically significant. The foliage biomass varied from 3.26–8.08 t ha^{-1} at the undisturbed and disturbed forest sites and it was significantly ($P < 0.05$) different among the two sites. Similar to branch and stem, it was also higher (148%) at the undisturbed forest site as compared to the disturbed forest site. The root biomass ranged between 37.52–89.51 t ha^{-1} at disturbed and undisturbed forest sites. The root biomass varied (non-)significantly ($P = 0.06$) between different forest sites, although it was 139% more at the undisturbed forest in comparison to the disturbed forest (Fig. 2).

Biomass allocation in different ground (herbaceous and litter) layer for disturbed and undisturbed sites

In this study, herbaceous shoot biomass differ significantly ($P < 0.05$) between the two forest sites, and was measured 61% higher at disturbed forest as compared to the

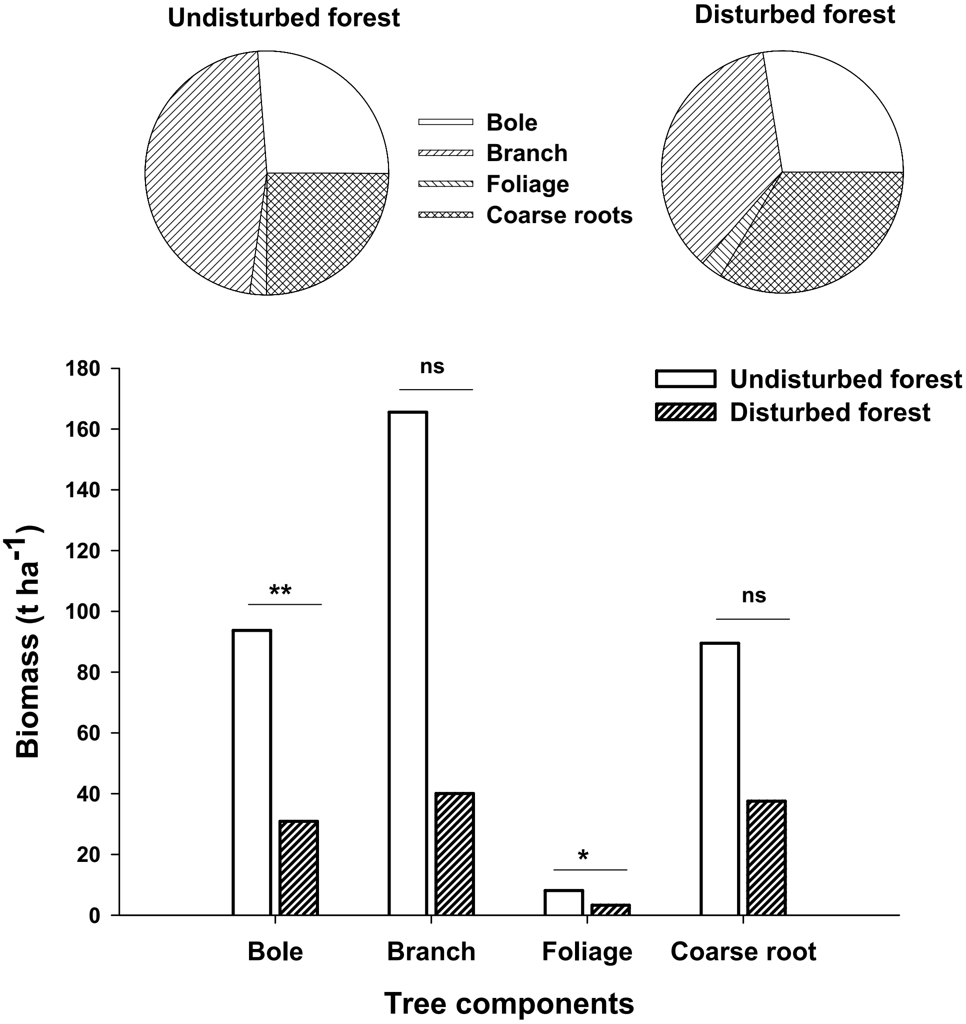

Fig. 2 Biomass allocation in different components (i.e., bole, branch, foliage and course roots) of tree vegetation under undisturbed and disturbed forests. Pie chart represent percentage distribution of biomass among different tree components. *, ** and ns represent significance level at $P < 0.05$, $P < 0.01$ and non-significant levels. (Based on Manutai et al. 2022)

undisturbed forest (Fig. 3). Contrary to this, total litter biomass varied significantly ($P < 0.05$) between different forest (Fig. 3), and was found 88% higher at the undisturbed forest (3.29 t ha^{-1}) as compared to the disturbed forest (1.75 t ha^{-1}).

Biomass allocation in different vegetation components for disturbed and undisturbed sites

The total biomass in the forest under study was 360.38 t ha^{-1} and 113.99 t ha^{-1}, respectively, at the undisturbed and disturbed forest sites (Fig. 4). Of the total biomass 270.87 t ha^{-1} and 89.51 t ha^{-1} respectively, was in above-ground and in the below-ground components at undisturbed forest, the share of by above- and below-ground components were 75.16 and 24.84%, respectively, to the total biomass (Fig. 4). Among the dominant species present at undisturbed sites, *Haldina cordifolia* had the highest biomass (97.52 t ha^{-1}) followed by *S. robusta* (72.58 t ha^{-1}) and *C. collinus* (53.30 t ha^{-1}), which respectively corresponded to 27, 20 and 15% of the total biomass of the undisturbed forest site (data not shown). Of the total biomass measured for disturbed forest, 76.47 t ha^{-1} was in above-ground and 37.52 t ha^{-1} in below-ground which corresponded to 67.08 and 32.92%, respectively in above- and below-ground components. Different trees species reflected differences in total biomass, and it was 77.87 t ha^{-1} for *T. tomentosa*, 19.98 t ha^{-1} for *E. laevis* and 6.58 t ha^{-1} for *Buchanania lanzan* among the dominant species at disturbed sites (data not shown). These species, respectively contributed 70%, 18% and 6% to the total forest biomass at the disturbed forest site. The share of tree layer to the total biomass was 98–99% and the remaining 1–2% was by litter mass and herbaceous layer (Fig. 4).

Discussion

In the present study, a considerable difference in the biomass and its allocation in different vegetation components due to the disturbance were observed. Disturbed forests had lower

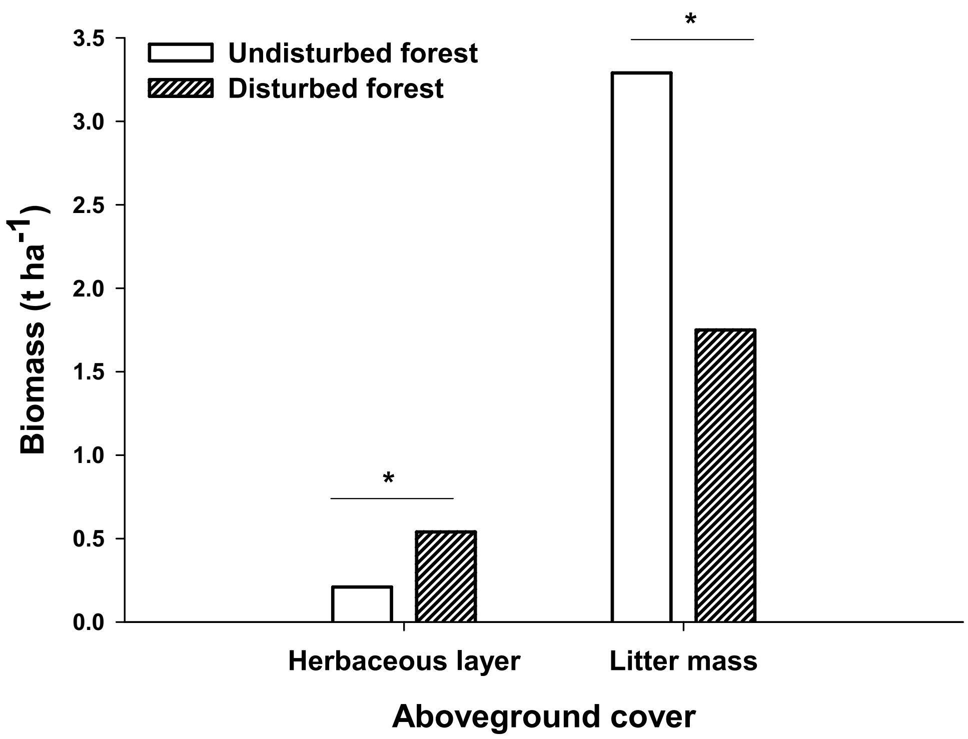

Fig. 3 Biomass allocation in different aboveground cover of the undisturbed and disturbed forests. * represents significance level at $P<0.05$. (Based on Manutai et al. 2022)

biomass and more allocation towards the below-ground components. Biomass allocation to different vegetation components is determined by the climatic conditions and disturbance regimes (Markesteijn and Poorter 2009). Brown and Lugo (1982) obtained an inverted U-shaped curve for the T/P ratio (where T represents mean annual temperature and P is total annual rainfall), with peak biomass values in the area of tropical humid forest type and lower values in wetter and drier forests. Using the relationship, $y=596+478 \log x-224 x$; where y = total biomass (t ha^{-1}), and x = T/P multiplied by 100, given by Brown and Lugo (1982), the expected biomass for the present forest (T/P = 2.13, T = 26 °C and P = 1221 mm) is about 275.84 t ha^{-1}.

Total biomass values for certain tropical forests are compared in Table 1. Total biomass ranged from 78–320 t ha^{-1} in most of the dry forests and 269–1186 t ha^{-1} in tropical moist forests (Murphy and Lugo 1986a). Total biomass in moist tropical forests was between 452 and 960 t ha^{-1}(Gautam and Mandal 2018). Total biomass in the present study was 114 t and 360.38 t ha^{-1}. Rai and Proctor (1986) have reported 434–669 t ha^{-1} total biomass for tropical rain forests of India (Karnataka). Above-ground biomass in the present study (76.47–270.87 t ha^{-1}) was towards the middle of the range (28–513 t ha^{-1}) reported for a variety of tropical forests (Table 1). Global pattern of above-ground biomass in tropical dry and wet forests is 30–273 t ha^{-1} and 213–1173 t ha^{-1}, respectively (Murphy and Lugo 1986b).

The distribution of total biomass and the above-ground biomass in different parts of the vegetation is compared in Table 1. The allocation of biomass to different parts of Sal, pine and oak forests was maximum in boles and minimum in foliage, however, in all the dry forests the branches contributed maximum to the total above-ground biomass. Data in Table 1 reveals that there is a wide range of variations in above-ground biomass (3-788 t ha^{-1}) as well as total biomass (47.7–960 t ha^{-1}). The above-ground biomass and total biomass in the present study was 76.47–270.87 t ha^{-1} and 114–360 t ha^{-1}, respectively.

In the present study, the mean leaf biomass was 5.67 t ha^{-1} (2–7 t ha^{-1}) and the total biomass of leaves and boles ranged between 70.92–259.29 t ha^{-1}, compared with the range (28–266 t ha^{-1}) reported for a number of tropical dry forests (Murphy and Lugo 1986b). The contribution of coarse root to total biomass in the present study was 24–33%. This value is compared to the reported range of 8–50% for tropical dry woodlands (Gautam and Mandal 2018). Brown and Lugo (1982) reported average contribution of roots in the range of 33% for humid whereas for dry tropical forests, it was 16%. Such observations were also reported for different Sal forests of the dry tropical regions (Raj and Jhariya 2021b).

The above-ground herbaceous biomass ranged from 0.21–0.54 t ha^{-1} in this study. The above-ground herbaceous biomass in tropical dry forest was observed as 0.29–0.42 t ha^{-1} (Singh Singh 1991). Singh et al. (2017) also reported herbaceous biomass in the range of 0.02 to 0.52 t ha^{-1} in the dry deciduous forest-savanna-grassland continuum of India. Gautam and Mandal (2018) have reported the herbaceous biomass

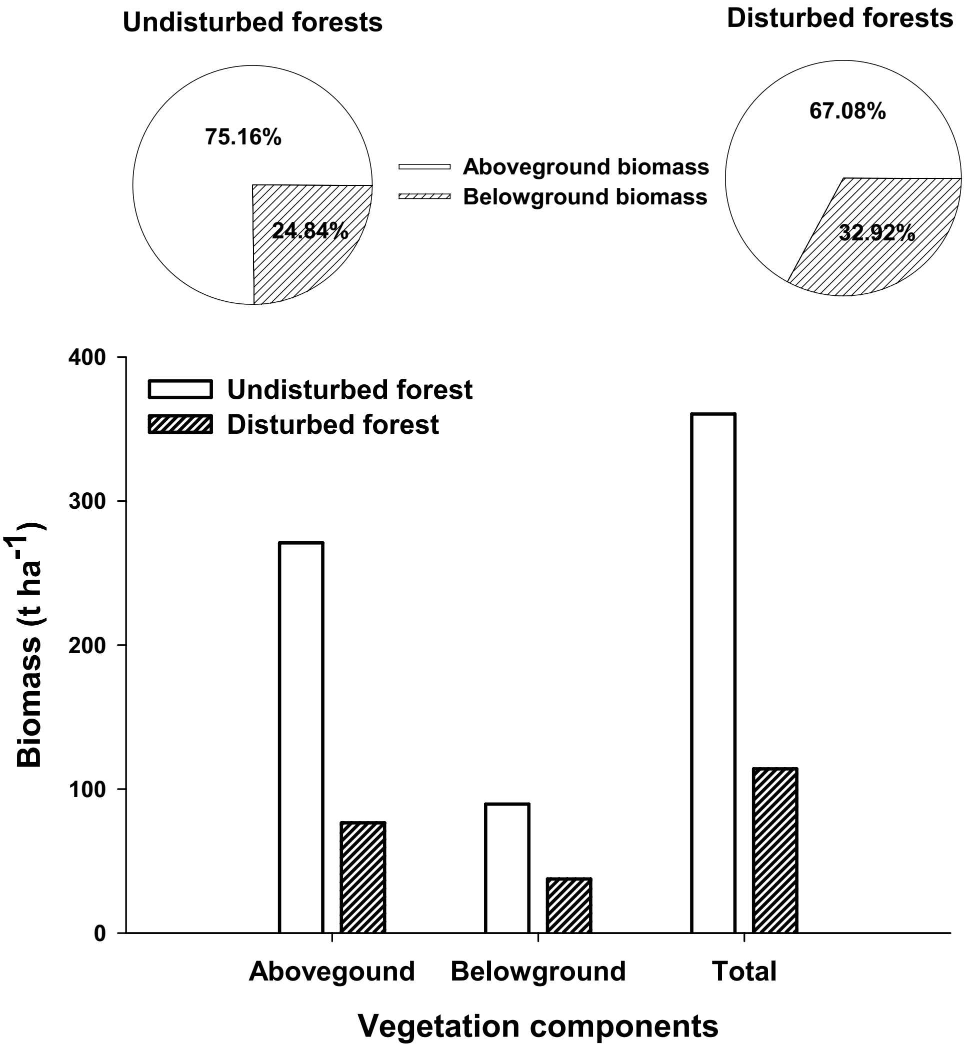

Fig. 4 Biomass allocation in above-ground and below-ground components of undisturbed and disturbed forests. Pie chart represent percentage distribution of biomass among different vegetation components. (Based on Manutai et al. 2022)

between 1.2–1.4 t ha^{-1} for the disturbed and undisturbed sites in tropical moist deciduous forest of Nepal. The herbaceous biomass in Central Himalayan Sal, pine and oak forests was, respectively, 2.0, 2.0 and 1.0 t ha^{-1} (Chaturvedi and Singh 1987; Rawat and Singh 1988; Singh and Singh 1989). The increase in herbaceous biomass with the disturbance gradient as observed in this study was also reported by Singh et al. (2017). Exposure to sunlight and least competition with the tree species for different resources may help in increasing the herbaceous cover and biomass in the disturbed areas (Donzelli et al. 2013; Singh et al. 2017). Thus, the disturbance events may promote the growth of herbaceous vegetation, biomass allocation to below-ground components and change in vegetation communities in tropical dry deciduous forests of India with the passage of time.

Conclusions

Based on the present study, we conclude that the anthropogenic disturbances are significantly affecting the total biomass and its allocation to different vegetation components of the tropical dry forests. Impact of disturbance is more pronounced on the above-ground components. Under disturbance, plants are comparatively allocating more biomass to the below-ground and herbaceous layers. Among the different above-ground components, branches and boles contribute more to the total biomass under undisturbed conditions whereas branches and roots contribute more under disturbed conditions. Thus, for biomass and C-sequestration, trees having tendency to invest in root

Table 1 Comparative account of stand biomass (t ha^{-1}) of certain tropical forests and plantations of the world

Forest type	Location	Stand Biomass (t ha^{-1})			References
		Above-ground	Below-ground	Total	
Sub-tropical wet	India	420–649	14–20	434–669	Rai and Proctor (1986)
Tropical dry	Global pattern	3–273	10–45	78–320	Murphy and Lugo (1986a)
Sub-tropical dry	Puerto Rico Guanica	53	45	98	Murphy and Lugo (1986b)
Tropical dry	India	42–78	9–16	53–94	Gautam and Mandal (2018)
Tropical dry	India	67.4	–	–	Haripriya (2000)
Tropical moist	Thailand	167	–	–	Clark et al. (2001)
Tropical dry	Puerto Rica	84.8	–	–	Do
Tropical dry	Mexico	126	17.1	143.1	Jaramillo et al. (2003)
Tropical dry	Chamela, Jalisco, Mexico	–	–	47.74	Do
Tropical dry	West Africa	29.88	–	–	Thenkabail et al. (2004)
Tropical rain	Wisconsin, USA	1–358	–	–	Zheng et al. (2004)
Tropical dry	Nigeria	–	–	49.22–141.29	Mbaekwe and Mackenzie (2008)
Tropical dry	India	71.94–162.91	13.97–30.02	85.78–192.93	Singh et al. (2008)
Tropical wet evergreen	India	–	–	440–588	Swamy et al. (2010)
Tropical dry	India	83–87	13–17	183.7–298.3	Kumar et al. (2011)
Tropical dry	Baja California Sur	40.06	–	–	Navar (2011)
Tropical dry	Vado Hondo, Sinaloa	47.81	–	–	Do
Tropical dry	Tiniaquis, Sinaloa	58.15	–	–	Do
Tropical dry	Morelos	14.13	–	–	Do
Tropical dry deciduous	India (Temporal dynamics)	289–292	–	–	Goparaju et al. (2021)
Tropical dry	India	76.47–270.87	37.52–89.51	114–360	Present study

components can be recommended for restoring degraded or disturbed forest ecosystems.

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Data availability The data of the study can be made available on genuine request to the corresponding author.

Declarations

Conflict of interest The authors declare that they do not have known competing financial interests or personal relationships that could have appeared to influence the present work.

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