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Tree species composition, regeneration and diversity of an Indian dry tropical forest protected area

BIPLAB BABOO[1], R. SAGAR[2*], S. S. BARGALI[3] & HARIOM VERMA[2]

[1]*Department of Forestry, Indira Gandhi Agricultural University, Raipur, India*
[2]*Department of Botany, Kumaun University, Nainital, India*
[3]*Department of Botany, Banaras Hindu University, Varanasi, India*

Abstract: Protected areas (PAs) are suggested as boon for biodiversity because they preserve genetic diversity, species populations and maintain ecosystem sustainability. In the Bhoramdeo wildlife sanctuary of central India, four locations differing in anthropogenic disturbances were selected. At each location, three homogeneous plots were marked to study tree species composition, diversity and regeneration against anthropogenic pressure. Within each plot 10 quadrats of 10 × 10 m in size were established and diameter of all stems of each species for each life stage was determined. From the entire 1.2 ha areas total 65 species, 273890 stems and 23.8 m^2 ha^{-1} basal area (≥ 30 cm height) were recorded. Anthropogenic disturbances changed species composition, limited regeneration and reduced species diversity. Bray-Curtis analysis of each life cycle stage for each location suggested temporal dynamism in species composition. Study showed negative relationship between seedlings species diversity and conservation focussed species populations. The negative relationships of pole's species number and stems with averaged tree canopy size, and disturbance scores with seedling's species number, Shannon index, and that of pole's stem suggested for selective harvesting of old age trees in addition to stop the practice of harvesting of juveniles for sustainable management of protected forests of dry tropics.

Key words: Disturbance, dry tropics, population depletion, protected area networks, regeneration, species diversity.

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Introduction

Tropical forests cover merely 7% of the Earth's land surface and harbour more than half of the world's species (Wilson 1988). These forests are highly threatened by human activities (Htun *et al.* 2011). Researchers predicted that the clearing of half of the world's residual forests would remove 85% of all the species inhabited by them (Pimm & Raven 2000). Data from tropical forest alone suggested continuous loss of more than one higher plant species per day (Myers 1990), disappearance of 20 ha forests and destruction of more than 1800 populations per hour (Hughes *et al.* 1997) and loss of species populations at a percentage rate 3–8 times than the rate of species extinction due to natural and biotic disturbances as well as habitat alterations (Costanza *et al.* 1997). Poverty, population pressure, agricultural expansion and intensification and development of infrastructure have been suggested as major threats to biodiversity in the tropics (Davidar *et al.* 2010).

Globally, 52% of total forests are tropical and more than 42% of these have been categorised as dry forest (Holdridge 1967). In India, tropical forest covers 80.69% of the total forest land and

Corresponding Author; e-mail: sagar@bhu.ac.in

tropical dry deciduous forest accounts for 41.87% of total forest (FSI 2011). Forests and people are tightly coupled in this country. Studies have also reported that millions of people reside within or close to protected areas (PAs) and harvest forest products (Davidar *et al.* 2010). The activities occurring in the dry deciduous forests include exploitation through commercial logging, seasonally set forest fires, fuel wood removal, charcoal production, cattle grazing, pruning and land clearing for agricultural activities (Bhuyan *et al.* 2003; Sagar *et al.* 2003). Studies have shown that these disturbances changed the forest composition, structure (Bhuyan *et al.* 2003; Sagar *et al.* 2003) and reduced the species diversity (Makana & Thomas 2006; Sagar & Singh 2005) by restricting size of forest patches (Krishana *et al.* 2014). Continued increase in the human population together with livestock populations, the pressure on these forests in terms of intensive livestock grazing, fuel wood and timber harvesting for their energy and income generation are mounting and consequently resulting into the reduced carrying capacity of these forests (Davidar *et al.* 2010; Sagar & Singh 2004). As for as quantification of load is concerned on the dry deciduous forests of central India; the labour population associated in quarrying alone use 417 tonnes of fuel wood per month (Sagar & Singh 2004; Singh *et al.* 1991). A grazing pressure of 0.43 ha per cattle (Sagar & Singh 2006; Upadhyay & Srivastava 1980) and reduction of forests at a rate of 0.22 km^2 per year (Krishana *et al.* 2014) have been reported. Due to accelerated anthropogenic pressures, the dry deciduous forests of central India are extremely eroded (Champion & Seth 1968) and they are quickly shifting into dry deciduous scrub, savannah and grasslands (Champion & Seth 1968; Sagar & Singh 2004, 2005, 2006) with varying patch sizes (Krishana *et al.* 2014).

Protected areas (PAs) have been suggested globally as a cornerstone for biodiversity conservation and management (Clark *et al.* 2013; Houehanou *et al.* 2012). The PAs maintain and promote the population of native species, composition of communities, conserve the genetic diversity of all resident species (Singh *et al.* 2014) and permits the sustainable flow of natural goods and services to fulfil the requirements of the local residents (Singh *et al.* 2014). Also, the significance of PAs to protect biodiversity has been defended in Aichi Target 11 of the Convention on Biological Diversity (CBD), which emphasised that by 2020 at least 17% of terrestrial as well as aquatic habitats should be conserved by PAs or other alike area-dependent conservation strategies. Because of sensible awareness generated by CBD, presently PAs are covering 12.7% of the Earth's land surface which are dedicated for conservation and management of biodiversity (Clark *et al.* 2013; Htun *et al.* 2011).

In 1992, the World Conservation Monitoring Centre carried out a study on the status of plants and animals from the PAs of tropics. Based on such preliminary observation, only 5% of the PAs in the tropical ecosystems harboured one or more groups of organisms. This report also pointed out that the PAs in tropical regions are poorly described in terms of their plant and animals (Hawksworth *et al.* 1995) and due to this it is difficult to assess the effectiveness of the PAs in tropical ecosystem for resource generation. Nevertheless, modules of PAs which have already been degraded may need rehabilitative measures to restore them to their natural state (Singh *et al.* 2014). Consequently, it is essential to understand the species population structure, composition and diversity of PAs in view of conservation and management of biodiversity for the needs of the local peoples residing in and outside of PAs (Davidar *et al.* 2010).

Baseline data on forest structure, composition and diversity at different levels of human disturbances would facilitate creation and implementation of more effective conservation measures to protect biodiversity of PAs (Sagar & Singh 2006). To comprehend the response of forest vegetation to different intensities of anthropogenic disturbances would be helpful in formulation of strategies and efficient conservation efforts to protect and manage the biodiversity within or outside the PAs (Bhuyan *et al.* 2003; James *et al.* 2001) for sustainable utilization of resources (Htun *et al.* 2011). Looking into these accounts, this study was conducted to answer: (i) do anthropogenic disturbances change the forest species composition, restrict the regeneration status of species and reduce species diversity? and (ii) identification of possible strategy to increase species diversity in the protected areas of the dry tropics.

Materials and Methods

Study sites

The study was conducted in Bhoramdeo, Salehwara, Jamunpani and Bandha (22°10′N and 80°10′E) sites in the Bhoramdeo Wildlife

Sanctuary of Chhattisgarh in year 2009. Bhoramdeo Wildlife sanctuary is located in the dry tropical forest of Vindhyan highland which was established in year 2001 with a total area of 163.8 Km^2. The purpose of establishment of the sanctuary was to protect and propagate the dry tropic's spectacular flora (*Acacia catechu*, *Adina cordifolia*, *Briedelia retusa*, *Hardwickia binata*, *Ougenia oogeinensis*, *Terminalia alata*), fauna (leopard, hyena, fox, bear, chital, wild buffalo, nilgai) and indigenous Baigas and Gond tribes (MoEF 2002). During the settlement of claims, prior to final notification of the sanctuary, the Collector in consultation with the Chief Wildlife Warden as well as recommendation of the State Board for Wildlife permitted certain rights (*viz.* grazing or any removal or exploitation of wildlife or forest produce) to the tribes in or over any land within the limits of the sanctuary (MoEF 2002). The tribes and their activities were allowed because of the pre-established thought that the tribal peoples and their rights in and around the established Wildlife sanctuary never challenge the goals of biodiversity conservation. Nevertheless, the integration of such peoples with biodiversity could be an indicator of the truly sustainable development of the PAs (Sobrevila 2008).

Physiographically, the area is undulating and characterised by hillocks. The altitude varies from 600 to 894 m a.s.l. Granite and cyst basic and ultrabasic are major rocks. The cyst rocks are characterised by biotitic cyst, Chlorite and micacyst. The soil belongs to Entisols and Ultisols. Entisols are characterized by extreme depth and gray to grayish brown in colour. Among the physico-chemical characteristics, sand content ranged between 16–17%, silt 35–36%, clay 47–48%, bulk density 0.87–0.91 g cm^{-3}, organic-C 1.73–1.76%, total-N 0.14–0.16% and soil pH ranged from 7.57–7.67. Thus, the soil is very poor in nutrients, slightly alkaline and spatially less variable.

Study area experiences a dry tropical monsoon climate with three distinct seasons; rainy (monsoon) (mid-June to September), winter (November to February), and summer (April to mid-June). October and March are transition periods, respectively between rainy and winter, and winter and summer, seasons. Mean annual rainfall varies from 1250 to 1380 mm, of which about 86% is received from southwest monsoon during June–August. Mean monthly annual temperature ranges from 16.5 °C (December) to 40.8 °C (May). The mean annual maximum and minimum temperature are 43.4 °C (May) and 7.9 °C (December). Relative humidity ranges between 27 (May) to 86% (August). The potential natural vegetation of the region is characterized by dry tropical deciduous forest. *Shorea robusta, Anogeissus latifolia, Lagerstroemia parviflora, Terminalia tomentosa, Hardwickia binata, Boswellia serrata, Buchanania lanzan, Acacia catechu*, etc. are the important tree species which exhibit local dominance (Champion & Seth 1968; Jhariya *et al.* 2012; Sagar *et al.* 2003).

Sampling

On the basis of reconnaissance survey of the sanctuary, four sites were selected to represent the entire range of conditions in terms of tree species composition and disturbance settings. The sites were categorized according to the scale of anthropogenic pressure they experience. These forest sites experience disturbances with varying degree. The anthropogenic pressures include extraction of ground cover by grazers and scraping by local people for grass collection in summer, cutting and lopping of poles and trees by tribes for fuel wood and fodder requirements. The anthropogenic pressures with estimated relative impact, on each of the four sites are illustrated in Table 1. The site with minimum animal popu-lation, number of houses and human population was given the impact factor 1. Impacts of anthropogenic pressure for the sites were calculated as ratios of the animal population of the other sites to the animal population of this site (Sagar *et al.* 2003; Sagar & Singh 2005). For example, animal population of the Bhoramdeo site was 6859 (maximum) whereas the same Bandha site was 1325. Based on this, the calculated impact of animal population for Bandha was 1, and that for Bhoramdeo was 5.18 (6859/1325). It means that Bhoramdeo site is more than five times disturbed than the Bandha site due to animals only. In a similar way, impact of cutting and lopping was relativized with the help of pole density, and that of grazing and browsing by seedling density (Sagar *et al.* 2003; Sagar & Singh 2005). The disturbance score range of a particular element suggests that higher score value is corresponding times greater than the overall minimum score value; the disturbances gradually increase in intensity from Bandha to Bhoramdeo site (Table 1).

At each site three homogeneous stands (replicates) experiencing similar anthropogenic interferences were selected. Tree species were categorized into three life cycle stages: adults (stems ≥ 10 cm dbh), poles (stems < 10 to ≥ 3.2 cm

Table 1. Disturbance regime (estimated, relative impact factors) on each of the four forest sites of Bhoramdeo wildlife sanctuary in Chhattisgarh, India. The sites bearing the numerical value for a particular disturbance element is corresponding times higher than the site experiencing numerical value 1 within a disturbance element.

Sources of disturbance	Bandha	Jamun-pani	Saleh-wara	Bhoram-deo
Number of house	1	4	4	5
Human population	1	3	4	6
Animal population	1	1	3	5
Grazing intensity	2	1	3	3
Cutting and lopping	2	1	1	1
Total scores	7	11	15	20

dbh) and seedlings (stems < 3.2 cm dbh but ≥ 30 cm height from the ground). Within each stand, 10 quadrats each of 10 × 10 m area were randomly placed for sampling of adults and poles. Within each 10 × 10 m area, a 2 × 2 m area was marked for the sampling of seedlings. The diameter of all stems over bark was enumerated by species. Diameters of adults and poles were measured at 1.37 m from the ground and for seedlings it was measured at 10 cm above the ground. Total number of stems and basal area of seedlings were scaled up similar to adults and poles by multiplying with 25.

Data analyses

Number of species, stem density, basal area for each 0.1 ha area for each site and each tree life cycle stage were calculated. The Importance Value Index (summation of relative frequency + relative density + relative basal area) for each species and for each tree life cycle stage on each site was determined. The dominant and co-dominant species of each site for each life cycle stage were defined on the basis of Importance Value Index (IVI) of the species falling in respective life cycle stages. The species having highest IVI in respective life cycle stage was defined as dominant and that having second IVI was defined as co-dominant species of that life cycle stage. To detect the similarity in species composition across the sites, Bray-Curtis similarity was performed with the help of Cluster analysis using PC-ORD software (McCune & Mefford 1999). In this analysis, IVI values of the component species distributed in three tree life cycle stages on each site were used. Further, the sites of each life cycle stage were ordinated by Non-metric multi-dimentional scaling (NMS) using PC-ORD software to identify the reason accountable for variation in species composition. The NMS axes scores were regressed with the soil parameters and disturbance scores with the help of SPSS software (SPSS 2014).

Species richness (number of species per unit area), equitability (distribution of abundances among the species) and Shannon–Wiener index as a measure of alpha diversity were calculated for each site in each tree life cycle stage using following equations:

$$H' = \sum_{i=1}^{s} pi \ln pi$$ (Shannon & Weaver 1949).

$$SR = \frac{S-1}{\ln N}$$ (Margalef 1958).

$$E = \frac{H'}{\ln S}$$ (Pielou 1966).

In the above equations; H' = Shannon-Wiener index, SR = index of species richness, E = index of evenness, S = number of species, N = number of stems, pi = proportion of stems belonging to species 'i' and ln = natural log. Additionally, the species diversity of the sites was compared using a K-dominance curve, wherein percentage cumulative importance value is plotted against log species rank (Platt *et al.* 1984; Sagar & Singh 2005).

Species population characteristic was categorised into four groups on the basis of the proportion of seedlings of a species in its total population (Sagar & Singh 2004): (i) a ratio representing 0.00 (zero) was considered as conservation focused species, (ii) a ratio of 1 was considered as newly–recruited species or immigrants from the neighbouring areas. The ratio between > 0.00 – < 1.00 for a species was designated as regenerating population which was further categorised into (iii) good reproducer (a ratio between ≥ 0.50 – < 1.00) and (iv) poor reproducer species (a ratio between >0.00 – <0.50); because it has been assumed that for normal replacement, the seedling population should consist of a minimum of more than 50% of the total population (seedlings + poles + adults) of a species

(Sagar & Singh 2004). The species representing 0.00 (zero) ratio were further confirmed by rigorous surveying the neighbour areas of the local sites to ovoid the error due to population regeneration of a species using gaps.

Data were subjected to analysis of variance (ANOVA) to understand the effects of degree of disturbance on species diversity parameters, number of stems and basal area of various tree life cycle stages. Correlation coefficients and linear regressions between studied environmental variables and response variables were established through SPSS statistical software package (SPSS 2014).

Results

Forest structure & composition

A total of 65 species and 273890 stems with 23.8 m^2 ha^{-1} basal area (species having ≥30 cm height) were recorded from the entire study plots (1.2 ha). Total number of species, stems and basal area varied from 36–47, 58550–90700 (Table S1) and 4.3–7.1 per site, respectively (Table 2). The numbers of species occurring as adults, poles and seedlings were highest at least disturbed Bandha site and lowest at highly disturbed Bhoramdeo site (Table S1). The numbers of species occurring either only as adults or only as poles were highest at drastically perturbed Bhoramdeo site. The numbers of species represented by only as seedlings were highest (10) at least disturbed Bandha site and lowest (01) at drastically disturbed Bhoramdeo site (Table S1).

Primary and secondary dominant species on each site and for each tree life cycle stage are presented in Fig. 1. In adult stage, *Boswellia serrata*, *Ougeinia oojeinensis*, *Buchanania lanzan* and *Lannea cormandelica* were primary dominant species at Bandha, Jamunpani, Salehwara and Bhoramdeo sites, respectively and these sites were respectively co-dominated by *Kydia calycina, Lannea coromandelica, Diospyrois melanoxylon* and *Lagerstroemia parviflora* species (Fig. 1). In pole stage, *Lagerstroemia parviflora* dominated at the Bandha and Bhoramdeo sites and it was a co-dominant species of Jamunpani site. *Diospyros melanoxylon* and *Anogeissus latifolia* were the dominant species of Jamunpani and Salehwara sites, respectively. Bandha, Salehwara and Bhoramdeo sites were correspondingly co-dominated by *Anogeissus latifolia, Ougeinia oojeinensis* and *Chloroxylon swietenia* species. In seedling stage, *Diospyros melanoxylon* dominated at the Bandha, Jamunpani and Bhoramdeo sites, while *Ougeinia oojeinensis* dominated at the Salehwara site. *Cassia fistula* was the secondary dominant species of Bandha and Jamunpani sites. *Anogeissus pendula* and *Chloroxylon swietenia*, respectively co-dominated at the Salehwara and Bhoramdeo sites (Fig. 1). The least and the highest disturbed sites were similar in their dominant species in lower diameter classes, while such sites were different in their co-dominant species in pole and seedling life cycle stages. This indicated change in species composition in near future, if current level of anthropogenic pressure will continue.

Table 2. Mean number of species, stems and basal area (m^2 ha^{-1}) of tree species in different tree life categories on four sites arranged in a gradient of anthropogenic pressure at Bhoramdeo wildlife sanctuary in Chhattisgarh, India. Numbers of species are in per 40 m^2 for seedlings and per 0.1 ha for adults and poles. Numbers of stems are in per 0.1 ha for all tree life stages. The values of basal area are on a site is averaged value of 30 quadrats. Values adjacent to means are SE.

Sites	Species	Stems	Basal area (m^2 ha^{-1})
Adults (stems ≥ 10 cm dbh)			
Bandha	16±3	753±151	2.50±0.31
Jamunpani	17±1	817±189	3.70±0.49
Salehwara	15±1	853±90	2.40±0.28
Bhoramdeo	15±1	697±126	2.10±0.21
Poles (stems < 10 to ≥ 3.2 cm dbh)			
Bandha	17±1	980±177	0.30±0.11
Jamunpani	13±5	647±184	2.00±0.10
Salehwara	14±1	800±254	0.31±0.10
Bhoramdeo	15±2	710±159	0.29±0.10
Seedlings (stems < 3.2 cm dbh but ≥ 30 cm height from the ground)			
Bandha	22±1	28917±2219	4.30±0.18
Jamunpani	11±4	23500±3660	3.00±1.30
Salehwara	17±1	23750±3753	2.81±0.10
Bhoramdeo	9±2	18417±4042	1.89±0.38

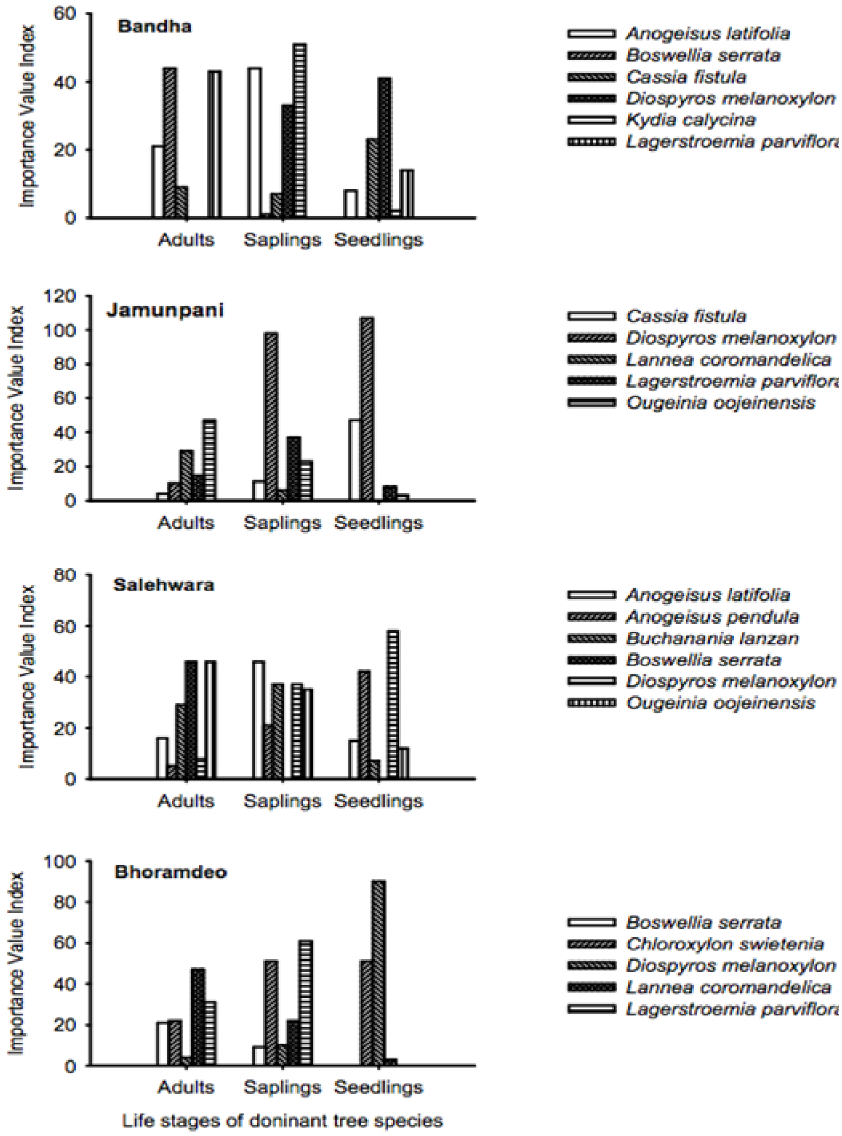

Fig. 1. Importance Value Index of the dominant and co-dominant species in three life cycle stages of tree species at each of the four sites in the Bhoramdeo wildlife sanctuary of Chhattisgarh, India. In the diagrams adults = stems ≥ 10 cm dbh, poles = stems < 10 to ≥ 3.2 cm dbh, and seedlings = stems < 3.2 cm dbh but ≥ 30 cm height from the ground.

The differences in species composition among tree life cycle stages across the four local sites, analysed by Bray-Curtis cluster analysing are illustrated in Fig. 2. The analysis suggested uniqueness in species composition among the sites for each tree life cycle stage, except for Bhoramdeo site which occupied bottom position in cluster analysis for each tree life cycle stage (Fig. 2). Further, sites were ordinated by using NMS ordination technique to understand the source of differences in species composition among the sites for studied tree life cycle stages. Percent variations in species composition explained by NMS axis-1 for adults, poles and seedlings were 52, 55 and 39, respectively. In same order, NMS axis–2 described 23, 24 and 32% variations in species composition for adults, poles and seedlings life cycle stages. NMS axes-1 of adults (r = –0.74, $P \leq 0.05$) and seedlings (r = –0.82, $P \leq 0.05$) and NMS axis–2 of poles (r = 0.68, $P \leq 0.05$) were negatively and significantly related with intensity of anthropogenic pressure. Hence, study revealed that local anthropogenic disturbances within the sanctuary induced differences in species compositions.

Table 3. Status of different tree species population categories at four sites of Bhoramdeo wildlife sanctuary in Chhattisgarh, India. Sites are in a gradient of anthropogenic disturbance.

Ratios of seedlings to the total population	Bandha	Jamun-pani	Saleh-wara	Bho-ramdeo
0.00 (Conservation focused species)	11	17	8	19
<0.50 (Poor reproducers)	11	18	8	20
0.50-0.99 (Good reproducers)	25	16	20	15
1.00 (Newly recruited from neighbor areas)	11	6	9	1

Population structure

From the entire study plots, a total of 22% (*viz.*, *Acacia leucophloea*, *Bauhinia malabarica*, *Bixa orellana*, *Boswellia serrata*, *Butea monosperma*, *Ceiba pentandra*, *Cochlospermum religiosum*, *Dalbergia latifolia*, *Dalbergia sissoo*, *Ficus religiosa*, *Garuga pinnata*, *Hardwickia binata*, *Semecarpus anacardium*, *Syzygium cumini*) species showed 0.00 (zero) seedling ratio to the total population and nine percent (*viz.*, *Aegle marmelos*, *Bauhinia variegata*, *Catunaregam spinosa*, *Ficus semicordata*, *Stereospermum xylocarpum* and *Tectona grandis*) species were newly recruited from the neighbouring areas (Table S1).

Site-wise numbers of conservation focussed, poorly reproduces, good reproducers and newly recruited species population varied from 8–19, 8–20, 15–25 and 1–11, respectively. The numbers of conservation focussed and poorly reproducer species populations were highest at severely disturbed Bhoramdeo site, while, numbers of good reproducers and newly recruited species populations were lowest at this site and highest at least disturbed Bandha site, indicating the impact of local anthropogenic pressure on population regeneration and recruitment (Table 3).

The total numbers of species, stems and basal area of adults, poles and seedlings of each site are shown in Table 2. The Pearson correlations of these variables and disturbance scores with that of soil variables are illustrated in Table 4. Results indicated that among different soil variables, increased soil sand and reduced clay contents due to anthropogenic disturbances controlled the variation in stems and basal area of adults, and basal area of poles (Table 4).

Table 4. Pearson correlation coefficient (r) indicating the relationships of sand, silt, clay and bulk density with that of adult's stems and basal area, pole's basal area and disturbance scores at Bhoramdeo wildlife sanctuary in Chhattisgarh, India.

Parameters	Adult stems	Adult basal area	Pole basal area	Disturbance scores
Sand	−0.60*	-0.16^{NS}	-0.46^{NS}	0.71*
Silt	−0.71*	-0.39^{NS}	-0.53^{NS}	0.59^{NS}
Clay	0.70*	0.33^{NS}	0.67*	−0.74*
Bulk density	−0.63*	−0.67*	-0.44^{NS}	0.68*

*$P \leq 0.05$ at $n = 12$; ^{NS}Not significant. The significance levels were corrected using Bonferroni test.

Species diversity

ANOVA showed that differences in Shannon-Wiener index ($F_{3,\,7}$ = 7.88, $P \leq 0.05$) and species richness ($F_{3,\,7}$ = 10.77, $P \leq 0.05$) of seedlings and adults basal area ($F_{3,\,7}$ = 7.02, $P \leq 0.05$) due to sites were significant. The patterns of Shannon-Wiener index, species richness and evenness for each tree life cycle stage are shown in Fig. 3. For adults, the values of Shannon-Wiener index, and evenness were highest at Bandha site and lowest at Bhoramdeo site which also showed lowest species richness (Fig. 3). For poles, the values of Shannon index, species richness and evenness were highest at least disturbed Bandha site. For seedlings, these indices consistently declined from least disturbed Bandha site to highly disturbed Bhoramdeo site (Fig. 3). Moreover, the differences in species diversity due to sites for adults, poles and seedlings, analysed by K-dominance curves are illustrated in Fig. 4, in which bottom curve represented highest diversity and uppermost curve indicated lowest diversity.

Species richness, Shannon-Wiener index and biomass of seedlings and stems of poles were linearly and negatively related with disturbance intensity (Fig. 5). The linear regression analysis

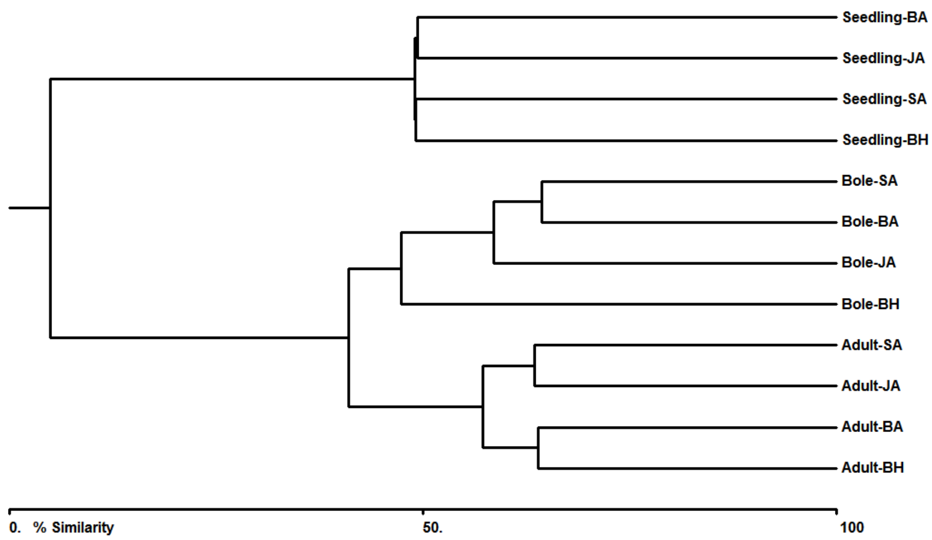

Fig. 2. Bray-Curtis cluster analysing indicating the similarity in species composition among different tree life stages of four local sites at the Bhoramdeo wildlife sanctuary in Chattisgarh, India. The suffix at the end of each tree life cycle stage represents the site initial (BH=Bhoramdeo, SA=Salehwara, JA=Jamunpani and BA=Bandha). In the diagrams adults = stems ≥ 10 cm dbh, poles = stems < 10 to ≥ 3.2 cm dbh, and seedlings = stems < 3.2 cm dbh but ≥ 30 cm height from the ground.

revealed that the ratio of averaged basal area to adult trees caused negative relationships with those of pole's species richness, stems and Shannon-Wiener index (Fig. 6). Thus, this study suggested that local anthropogenic disturbances in addition to old trees having larger canopy inhibited establishment of seedlings and poles in the PAs of the dry tropical forests. Thus, felling of old trees and restricting the collection of small size stems seem to be urgent requirement for the accumulation of species diversity within the protected area of dry tropical forests.

Discussion

Forests structure & composition

Differences in primary and secondary dominant species among tree life cycle stages within a site, and among the sites within a tree life cycle stage suggested spatio-temporal differences in community types because of long term anthropogenic events in the studied PAs of dry tropical forests. This pattern was also supported by the Bray-Curtis similarity analysis. Additionally, the significant relationships of disturbance scores with NMS axis-1 of adults and seedlings life cycle stages and with that of poles NMS axis-2 implied that local disturbances caused differences in species composition among the sites and tree life cycle stages. Interestingly, this study partially favoured assembly theory of Diamond (1975) who advocated for different species composition in spatially isolated communities. Moreover, Murphy & Lugo (1986) observed that no two dry tropical forest communities could be closely similar in their vegetation composition and structure due to chronic human interferences. Similarly, differences in species composition associated with local site conditions due to biotic disturbances were reported in outside the PAs (Davidar *et al*. 2010; Sagar *et al*. 2003; Sagar & Singh 2005). In this PAs, such differences could be due to fact of close relationship between local inhabitants and dry tropical forests communities over the forest history (Murphy & Lugo 1986; Sagar & Singh 2006).

As expected, highest mean stem density and basal area of all tree species were observed at least disturbed Bandha site (30650 per 0.1 ha and 7.1 $m^2\ ha^{-1}$) and lowest at highly disturbed Bhoramdeo site (19824 per 0.1 ha and 4.30 $m^2\ ha^{-1}$). Other studies have also reported lowest stem density and basal area on less disturbed location than the highly-perturbed location in dry tropics (Anitha *et al*. 2009; Bhuyan *et al*. 2003; Sagar *et al*. 2003; Sagar & Singh 2006). Increase in sand content and bulk density and reduction in clay contents due to anthropogenic disturbances reduced the basal area

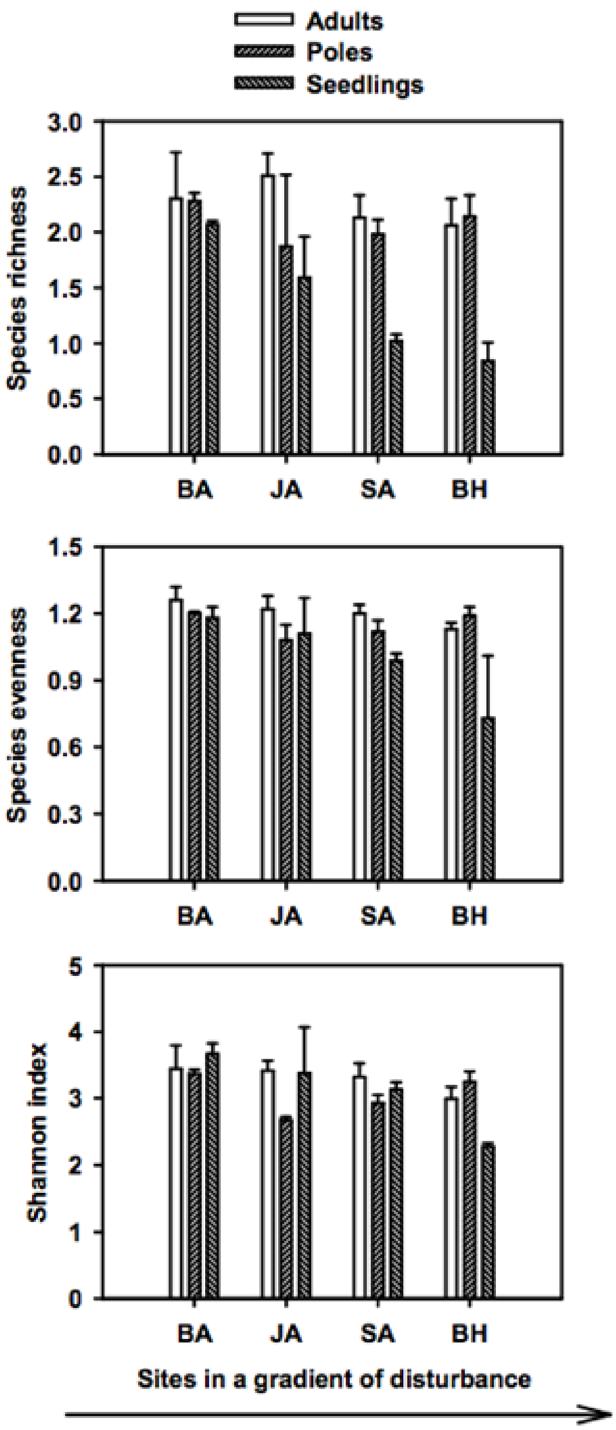

Fig. 3. Patterns of species richness, evenness and Shannon index of seedlings, poles and adults tree life cycle stages along the gradient of anthropogenic disturbance at Bhoramdeo wildlife sanctuary in Chhattisgarh, India. In the diagrams adults = stems ≥ 10 cm dbh, poles = stems < 10 to ≥ 3.2 cm dbh, and seedlings = stems < 3.2 cm dbh but ≥ 30 cm height from the ground.

of adults as well as poles and stems of adult tree life cycle stages in the studied wildlife sanctuary. Therefore, it can be argued that reduced soil clay and increased sand contents as a result of grazing and trampling intensity enhanced the soil compaction and the hydric deficiency of the local sites which in turn limited the tree growth in the studied PAs of dry tropical forests (Dagar 1987; Pandey & Singh 1991).

Population regeneration

Number of adults, poles and seedlings per unit area are being used to assess the regeneration status and potential of forest species (Sagar & Singh 2004; Saxena & Singh 1984), except certain pioneer species which can reproduce periodically using gaps. Presence of sufficient population of a species in adults, poles and seedlings stages could be an indicator of successful recruitment and regeneration of the forest species. Given that under normal conditions, the adult stems on a site or of a species comprise the reproductive pool. The number of poles on a site or of a species can be an immediate source of the adults, and seedlings can be a source of poles (Sagar & Singh 2005). Greater proportion of stems in lower diameter classes than the larger classes may represent the frequent and good regeneration. More stem numbers in middle diameter class and decreasing number of stem both towards the higher and the lower diameters classes comprise the infrequent regeneration (Benton & Werner 1976; Sagar & Singh 2006). A lower percentage of established seedlings than the poles can be interpreted as such species reproduced well in the immediate past and continue to do so at present, nevertheless at a lower rate, hence, it could be a suggestive of the poor regeneration.

Occurrence of only seedlings indicates that these species can be recent immigrants to the site and likely to become canopy/sub-canopy species in immediate future. The absence of established seedling species on a site suggests that such species reproduced better in the past but at present their regeneration has stopped, therefore, it could be a conservation focus species (Sagar & Singh 2004; Saxena & Singh 1984). In this study, the occurrence of maximum number of species only as adults, only as poles and less number of species only as seedlings at highly disturbed Bhoramdeo site inferred that these species reproduced better in the past but at present their regeneration has discontinued. Thus, the results further suggested

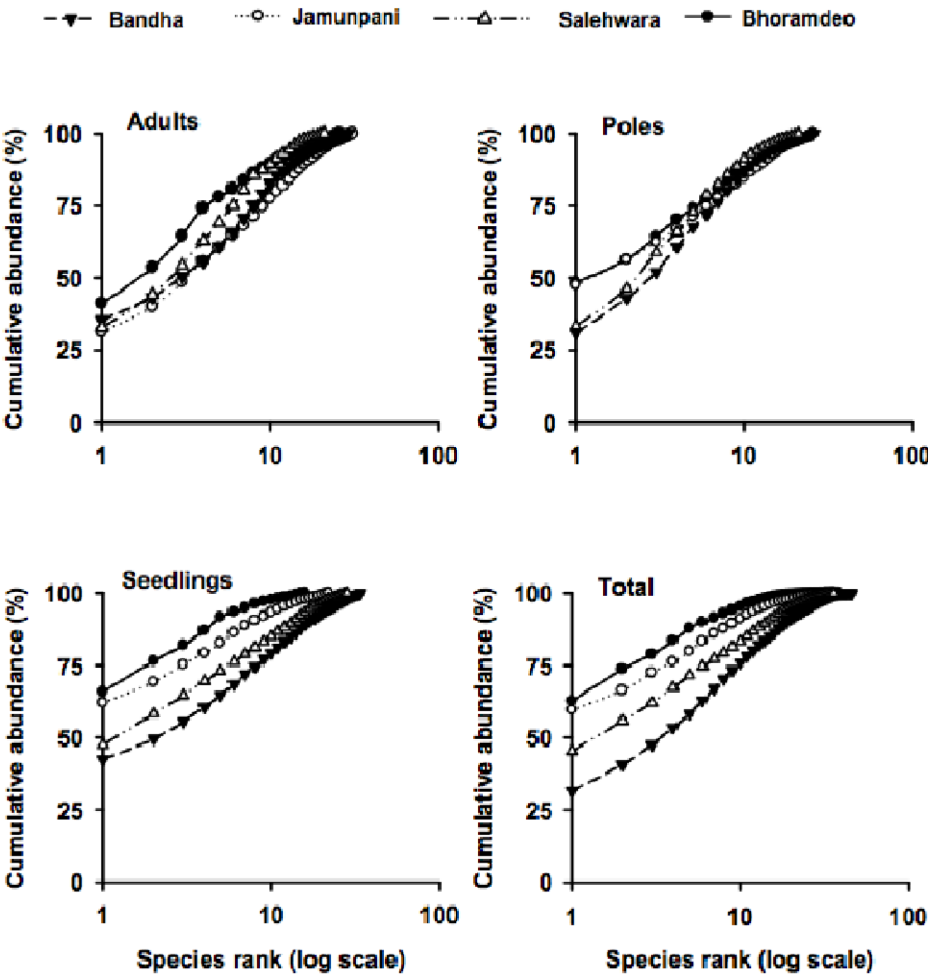

Fig. 4. *K*-dominance curves of the four sites in which percentage cumulative abundances is plotted against log of species rank for different tree life categories at Bhoramdeo wildlife sanctuary in Chhattisgarh, India. Bottom curve represents higher diversity and upper most curve lowest diversity. In the diagrams adults = stems ≥ 10 cm dbh, poles = stems < 10 to ≥ 3.2 cm dbh, and seedlings = stems < 3.2 cm dbh but ≥ 30 cm height from the ground.

that collection of seedlings and poles for the purpose of fire and fuelwood by local tribes could be harmful for species recruitment and regeneration in PAs as well. Further analysis suggested that a gradual reduction in poorly regenerating and conservation focussed species and consistently increasing good regenerating as well as newly recruited species (except Salehwara site) along the disturbance gradient (lowest to highest). Therefore, the local anthropogenic pressure could be a leading cause for the failure of population regeneration in the protected area. A similar pattern was also reported by Sagar & Singh (2004) outside the protected area located in the Sonebhadra districts of India. Evidently, the positive relationship between disturbance intensity and poorly regenerating species populations (r = 0.61, $P \leq 0.05$), and negative relations of disturbance intensity with good regenerating (r = −0.86, $P \leq 0.05$) and newly recruited (r = −0.91, $P \leq 0.05$) species populations supported our hypothesis that the anthropogenic pressure could be an ultimate cause for enhancing the number of poorly regenerating species and restricting the newly recruited and good regenerating species populations in the dry tropical forest vegetation.

As happens in other forests, illegal tree felling, severe lopping and harvesting of non-timber resources for fuel-wood and fodder collection, free range grazing, browsing by wild animals, and trampling by herds and feral are common practice

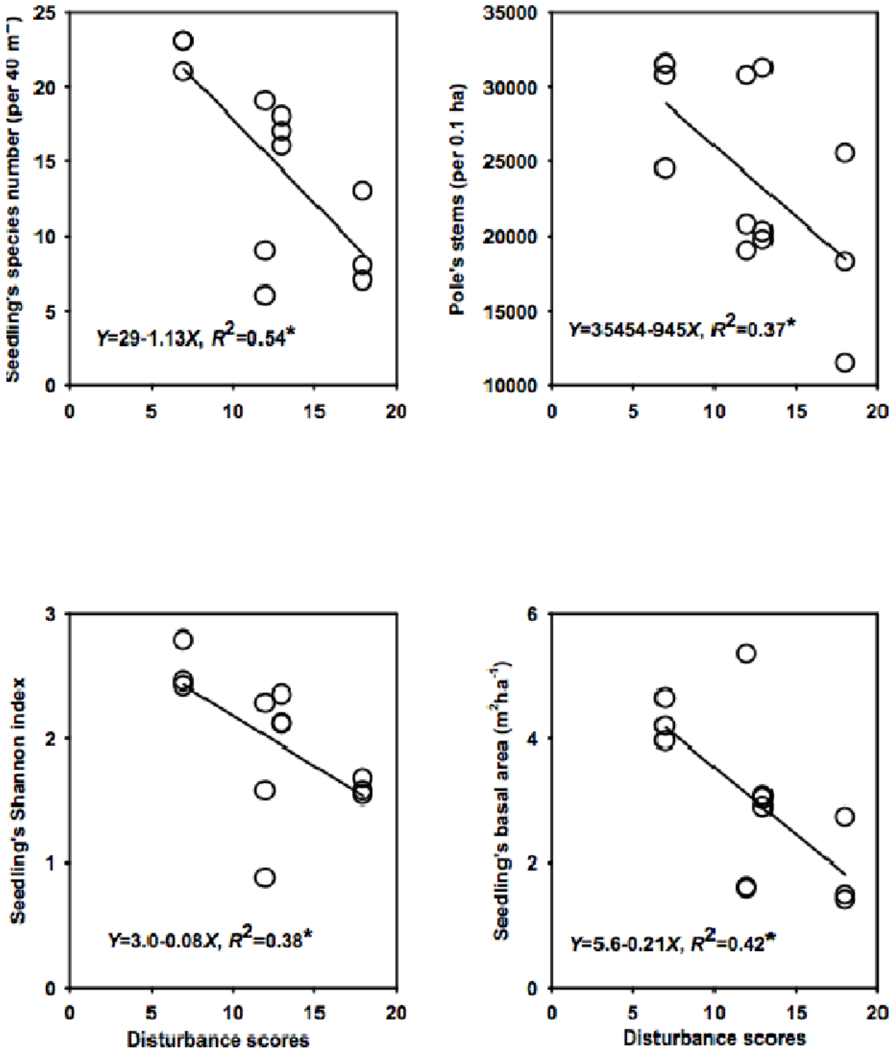

Fig. 5. Significant linear relationships of disturbance scores with seedling's species number, stems, Shannon index and basal area at Bhoramdeo wildlife sanctuary in Chhattisgarh, India. *significant at $P \leq 0.05$ after Bonferroni correction.

in dry tropics (Champion & Seth 1968; Sagar *et al.* 2003; Sagar & Singh 2004, 2006; Singh *et al.* 1991; Upadhyay & Srivastava 1980). It has been suggested that prolonged pressure of a single anthropogenic event may negatively change the soil and plant attributes of the forest ecosystem. For example, the repeated lopping of trees for leaf-fodder and fuelwood reduces the vigour as well as seed production (Saxena & Singh 1984). Extreme and repeated grazing solemnly thwarts the regeneration of woody elements (Saxena & Singh 1984). Cattle grazing and trampling change the soil structure by hardening and compact soil retains lower moisture content (Saxena & Singh 1984). As the survival of seedlings in dry tropical forest are mainly linked to seasonal drought (Gerhardt 1993) and cutting and lopping of trees and seedling damage by phytophagous insects could intensify the effect of drought on the regeneration (Lieberman & Li 1992). All these conditions change the local habitat and make it inappropriate for the seed germination and seedling establishment.

The tree species commonly preferred for fire-wood in this region are: *Adina cordifolia, Boswellia serrata, Hardwickia binata* and *Zizyphus glaberrima* (Harikant & Ghildiyal 1982; Sagar & Singh 2004). *H. binata, B. serrata, Dalbergia sissoo* and *Holoptelia integrifolia* are generally lopped for leaf fodder. *Cochlospermum religiosum, Ficus religiosa, Garuga pinnata, Hardwickia binata, Pterocarpus marsupium, Semecarpus anacardium*

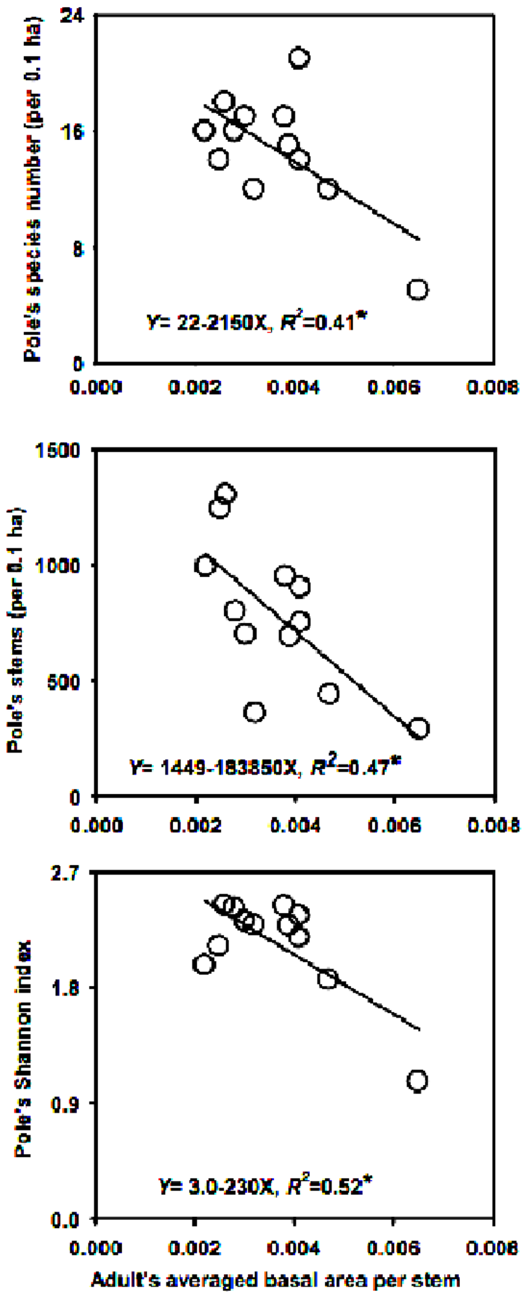

Fig. 6. Significant linear relationships of averaged adult's basal area per stem with pole's species number, stems and Shannon index at Bhoramdeo wildlife sanctuary in Chhattisgarh, India. *significant at$P \leq$0.05 after Bonferroni correction.

and *Terminalia. chebula* have very poor seed fertility (Duvall 2009; Troup 1921). The seeds of several species including *Adina cordifolia*, *Dalbergia sissoo*, *Ficus religiosa, Pterocarpus marsupium* and *Terminalia chebula* are susceptible to destruction by insects, birds, squirrels and other animals (Troup 1921). *Ceiba pentandra* is light-demanding, and its growth is poor and mortality is high for seedlings and poles in shaded locations (Duvall 2009). Seeds of *Semecarpus anacardium* and *Syzygium cumini* lose their viability very quickly (Duvall 2009). *Hardwickia binata* shows good seed years only once in three to five years (Sagar & Singh 2006). Since seed output is reduced due to lopping, the pressure of these anthropogenic factors mounts on the residual seed crop and the viable seed population may be further reduced. Interaction of these factors with local anthropogenic activities within the studied sanctuary further inhibited the recruitment and regeneration of certain species.

Species diversity

In contrast to intermediate disturbance hypothesis of Connell (1978) and Huston (1979), in our study the alpha diversity (Shannon-Wiener index) and its components (species richness and equability) for adults and seedlings life cycle stages declined consistently along the disturbance gradient. This is in conformity with other dry tropical forests studies within and outside the PAs (Chittibabu & Parthasarathy 2000; Clark *et al.* 2013; Htun *et al.* 2011; Houehanou *et al.* 2012; Sagar *et al.* 2003; Sagar & Singh 2004, 2006). The *K*-dominance curves for adults and seedlings also revealed maximum diversity at least disturbed Bandha site and lowest at highly disturbed Bhoramdeo site. The significant linear and negative relationships of disturbance intensity with seedling Shannon-Wiener index and species richness, provided clue for seedling mortality due to habitat conditions and anthropogenic activities (Sagar & Singh 2005). It has been further confirmed by the negative relationship between number of seedling species and conservation focussed species (r = −0.69, $P \leq$ 0.05), between number of seedling species and poorly regenerating (r = −0.70, $P \leq$ 0.05) species population, between seedling Shannon-Wiener index and conservation focussed species (r = −0.67, $P \leq$ 0.05) population, and between seedling Shannon index and poorly regenerating (r = −0.68, $P \leq$ 0.05) species population. Thus, the study pointed out that anthropogenic pressure caused the reduction of species diversity within the protected area, particularly seedlings, were more prone to such threats.

The less number of poles stems and diversity compared to seedlings and adults tree life cycle stages hints a warning for the sustainability of PAs because fuel wood and fodder extraction by the local people are major problem. In a similar study, relatively low seedling conversion to poles were reported and poles were not able to convert into adults on account of anthropogenic pressure (Sagar & Singh 2006). Illegal harvest of poles, density dependent mortality of seedlings and grazing were suggested as possible reasons for the low recruitment of poles (Sagar & Singh 2005, 2006). In addition, the significantly negative relationships of number of pole species, stems and Shannon-Wiener index with adult tree basal area per individual suggested that the old-age mature trees might have suppressed the growth of young individuals leading to the death of many pole stems, irrespective of species. Thus, selective felling of old-age and large-statured individuals may be needed for the sustainability of the PAs and the dry tropical forest.

Low occurrence of mature and old trees creates relatively open canopy, where the young trees grow successfully and do not compete with each other for water and nutrients. On the other hand, relatively high occurrence of mature and old trees in the forest results in comparatively dense canopy (Troup 1921) and in such situation, the poles and seedlings compete strongly with each other for moisture, nutrients and light, hence, become stressed (Anonymous 2014). The selective tree removal/cutting of mature and old trees from the forest creates canopy gap which may reduce the competition among the young trees for successful regeneration and recruitment. The created gaps allow rapid regeneration of existing young trees through natural seeding, sprouting, and suckering (Anonymous 2014; Sagar & Singh 2005) hence, improve the health and growth of the forests for further use by local residents residing inside or near to the PAs. Thus, this study may suggest that the PAs are not always serving as boon for biodiversity due to limitation in implementation of policies which need to be revised.

Conclusions

Study revealed that anthropogenic activities within the PAs of dry tropics limited the regeneration potential of selective species and consecutively reduced the species diversity. The selective felling of old-age trees and restriction for harvesting of young/juvenile individuals by local residents and raising of grasslands nearby their habitats to feed the livestock could be the prominent measures for sustainable development of the PAs of dry tropical forests.

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Supporting Information

Additional Supporting information may be found in the online version of this article.

Supplementary Table S1. Total number of stems (per 0.3 ha) of adults (stems ≥ 10 cm dbh), poles (stems < 10 to ≥ 3.2 cm dbh) and seedlings (stems < 3.2 cm dbh but ≥ 30 cm height from the ground) on four local sites of Bhoramdeo wildlife sanctuary in central India.