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Forest structure and anthropogenic pressures in the Pachmarhi biosphere reserve of India

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Abstract A critical first step in establishing biosphere reserves—under the Man and Biosphere Programme of UNESCO—is to generate baseline information for future courses of action. The present study aims to assess the structure and composition of forests—along with anthropogenic pressures mounting on these forests in the buffer zone of one such biosphere reserves—the Pachmarhi biosphere reserve of India. The quadrat method was employed for sampling vegetation, and information on anthropogenic pressures was collected by conducting interviews with local people and forest officials and collecting it from secondary sources. A total of 39 tree species were sampled in 82 quadrats; of these 26 tree species were in standing stage, 25 in sapling, and 35 in seedling. *Chloroxylon swietenia* emerged as the most dominant tree species having highest importance value index, followed by *Tectona grandis, Terminalia tomentosa*, and *Hardwickia binata*. Nine tree species and their saplings, including *Sterculia urens* and *Terminalia arjuna,* were exploited so badly that they were only found in the seedlings stage. The unavailability of standing trees of 12 important tree species including *Aegle marmelos* and *Phyllanthus emblica* indicates the intensity and gravity of anthropogenic pressures on these important tree species. If the present anthropogenic pressure continues, which has inhibited the regeneration of several tree species, then substantial negative ecological and societal consequences can be expected.

Keywords Pachmarhi biosphere reserve · Tropical forest · Forest composition · Forest structure · Regeneration · Anthropogenic pressures

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Introduction

Forests are enormously complex systems of highly heterogeneous plant communities that harbour biodiversity and maintain the ecological balance of any given area (Richards 1996; Majila and Kala 2010). Being the dynamic entities of nature, changes take place in their composition and structure with time and space. Forest structure and composition reflect their sustainability and resilience to anthropogenic pressures, including the status of current as well as past and future conditions of the forest stand, which are affected by various anthropogenic pressures and the changes in biotic and abiotic components over a period of time (Armesto and Pickett 1985; McNeely 1994; Karanth et al. 2006; Somanathan and Borges 2000; Majila and Kala 2010). Though changes in forest structure and composition over time are a natural phenomenon (Clement and Junqueira 2010), at present, the explosion of human population and subsequent changes in environment have accelerated the rate of changes in forest structure and composition (Kala and Dubey 2012). There are reports on the loss of valuable biodiversity even in wilderness areas (Myers et al. 2000; Brooks et al. 2006).

To safeguard the ecological integrity of natural resources, including forests, a large number of protected areas have been set aside across the globe. Establishing biosphere reserves, as designated under the UNESCO Man and Biosphere Programme, has been widely taken up to promote research, training, and awareness about the conservation of natural ecosystems and sustainable use of natural resources. In India, 18 such biosphere reserves have been established and are models for showing the balance between nature and man through sustainable development.

The Pachmarhi biosphere reserve (PBR) in Madhya Pradesh, one of the richest biodiversity spots in India, was declared as biosphere reserve in 1999. The Pachmarhi area is located somewhat in the middle of the north–south stretch of Indian Sub-continent, and encompasses the flora of both the Himalayas in the north and the Western and Eastern Ghats in the south, one of the causes of its rich biodiversity. Despite its unique locality, only limited studies have been carried out in this region (e.g., Oommachan et al. 1990; Jayson 1990; Kala 2011a, 2012, 2013a, b).

The managers of any protected area need detailed baseline information for setting priorities for future management actions. Lacking studies on people-forest interactions and subsequent anthropogenic pressures on forest structure and composition in the buffer zone area of PBR was one of the main reasons for taking up this study. The major aim was to assess the structure and composition of trees found in the buffer zone area of PBR. I also took a quantitative approach to find out the status of anthropogenic pressures on the forests, which has disturbed and changed the forest structure.

Materials and methods

Study area

The PBR, established on March 3, 1999, in the Satpura Range of Madhya Pradesh, India, is situated between 20°10′ to 22°50′N latitude and 77°45′ to 78°56′E longitude. It spans over 3 districts of Madhya Pradesh – Hoshangabad, Betul, and Chhindwara (Fig. 1). The total geographical area of PBR is 4987.38 km^2, of which 524.37 km^2 is in the core zone and the remaining 4462. 93 km^2 comprises the buffer zone (EPCO 2001; Kala 2013a, b). PBR includes three wildlife conservation units, the Satpura National Park (524.37 km^2), the Bori Wildlife Sanctuary (518.00 km^2), and the Pachmarhi Sanctuary (461.37 km^2). The Pachmarhi plateau is popularly known as “the Queen of the Satpuras”.

Satpura National Park is designated as the core zone of PBR and the remaining area, including the Bori and Pachmarhi sanctuaries, constitute the buffer zone. The core zone, being a national park, is legally protected area as per the Wildlife Protection Act 1972. In buffer zone areas, non-conservation activities are prohibited in view of maintaining the sustainability of natural resources for the benefit of local communities. Tigers, leopards, bison, barking deer, and rhesus macaques are found in the PBR. It is inhabited by number of tribal and non-tribal communities. Gond is the major tribal group in the study area. The livelihood of the Gond and Mawasi tribes depends on marginal agriculture, collection of minor forest products such as tendu patta and labor work. The rocky areas of Pachmarhi and Bori forests belong to the upper and lower Gondwana series, which contain sandstone and limestone. The temperature of PBR ranges from 11 to 42° C (Jayson 1990; Kala 2011b).

Survey methods

Forest structure and composition

To study the forest structure and composition in the buffer zone area of PBR, the vegetation survey was conducted in forests adjoining the 10 selected villages. Systematic surveys of tree species were conducted. The nomenclature and botanical identity of the trees follows Witt (1916), Haines (1916), and Roy et al. (1992). Nested plot sampling was used to collect information on the forest structure and composition following Misra (1968).

To sample trees, a quadrat size of 10 × 10 m was chosen and for saplings, and for seedlings, a 5 × 5 m quadrat size was used. In each quadrat, trees with ≥31.5 cm circumference at breast height (cbh) that is, 1.37 m from the ground, were individually measured for cbh. For tree species having cbh between 10.5 cm and 31.5 cm, both values were included, were considered as saplings; and tree species with less than 10.5 cm cbh was considered as seedlings. Individual trees were enumerated by species in each quadrat and a total of 82 plots were sampled during the survey.

Anthropogenic pressures

The information on anthropogenic pressures was collected from both secondary sources and interviews with local people and forest officials. Various anthropogenic pressures are visible in the form of livestock grazing, exploitation of useful tree species for food, fuel, and medicine, and harvesting practices of important medicinal plants. These discoveries were also recorded while the research team were laying quadrats for vegetation sampling. During the vegetation survey, the team also looked for signs of anthropogenic disturbances in the forests,

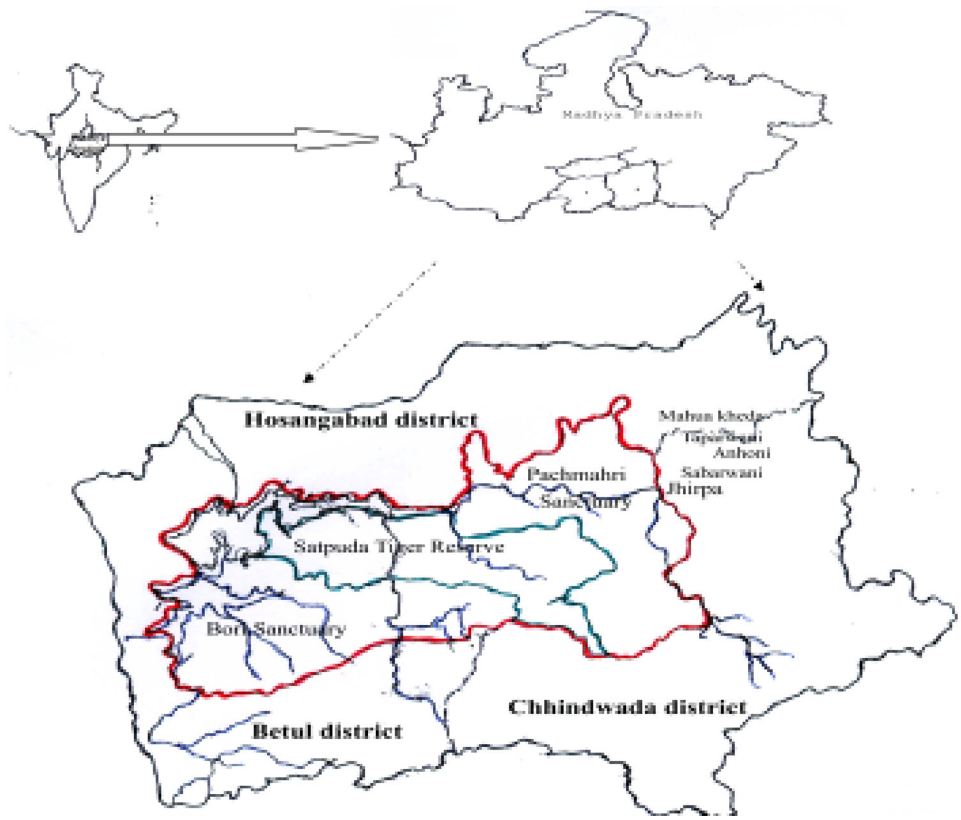

Fig. 1 Location map of the Pachmarhi biosphere reserve in India

which included lopped tree branches and stumps of the cut trees. The quantification of these signs of anthropogenic pressures was done by counting the number of individuals of cut and lopped trees of different plant species in each quadrat.

Data analysis

The density, relative density, relative dominance, relative frequency and important value index for each tree species was calculated following Misra (1968). Tree saplings and seedlings were also quantified in order to understand the regeneration pattern of the forests. The data collected on anthropogenic pressures were quantitatively analyzed by calculating the density of cut and lopped trees in the forests.

Results

Structure and composition of tree species

Overall, 39 tree species in standing, sapling and seedling stages were sampled in 82 quadrats laid out in the buffer zone areas of PBR during the present investigation. Of these, 26 tree species were in standing stage, 25 in sapling, and 35 in seedling. *Chloroxylon swietenia* emerged as the most dominant tree species in the forests of the PBR buffer zone with the highest importance value index (IVI), followed by *Tectona grandis, Terminalia tomentosa,* and *Hardwickia binata*. The saplings of *Chloroxylon swietenia* also remained highest in terms of IVI in the study area, followed by *Tectona grandis, Diospyros melanoxylon* and *Terminalia tomentosa* (Table 1).

Chloroxylon swietenia possessed the highest density (126 individuals/ha), followed by *Tectona grandis* (54 individuals/ha), and *Terminalia tomentosa* (43 individuals/ha) (Table 2). In addition to these species, the density of *Hardwickia binata* (27 individuals/ha), *Acacia catechu* (20 individuals/ha), and *Madhuca indica* (17 individuals/ha) was relatively higher in the study area. Through questionnaires and interviews, it was found that, except *Cordia macleodii* and *Bridelia retusa,* 37 tree species have been traditionally used by the local people.

Regeneration

Of the 25 tree species in the sapling stage, C*hloroxylon swietenia* had the highest IVI (89.22) and density (168 individuals/ha) of saplings, followed by *Tectona grandis* (IVI 45.46 and density 88 individuals/ha), *Diospyros melanoxylon* (IVI 32.62 and density 60 individuals/ha), and

Table 1 Status of trees and their saplings in Pachmarhi biosphere reserve of India in terms of relative density, relative dominance, relative frequency, and important value index (IVI)

Species	Standing trees				Tree sapling			
	Relative Density	Relative Dominance	Relative Frequency	IVI	Relative Density	Relative Dominance	Relative Frequency	IVI
Acacia catechu Willd.	5.39	2.36	5.71	13.46	4.47	5.30	6.45	16.22
Acacia leucophloea Willd.	1.01	0.69	1.71	3.41	0.47	0.52	1.08	2.07
Aegle marmelos (L.) Corr.	NA[a]	NA	NA	NA	0.24	0.10	0.54	0.87
Adina cordifolia Hook f.	0.34	0.19	0.57	1.10	0.24	0.25	0.54	1.02
Albizzia odoratissima (L. f.) Benth.	NA	NA	NA	NA	NA	NA	NA	NA
Albizzia procera (Roxb.) Benth.	0.34	0.11	0.57	1.02	NA	NA	NA	NA
Anogeissus latifolia Bedd.	3.03	1.49	3.43	7.94	3.53	4.07	3.76	11.37
*Azadirachta indic*a Juss.	NA	NA	NA	NA	NA	NA	NA	NA
Bauhinia racemosa Lamk.	0.34	0.15	0.57	1.06	0.71	0.21	1.08	1.99
Boswellia serrata Colebr.	0.34	0.15	0.57	1.06	NA	NA	NA	NA
Bridelia retusa Spr.	NA	NA	NA	NA	NA	NA	NA	NA
Buchanania lanzan Spr.	0.67	0.56	1.14	2.38	0.24	0.35	0.54	1.12
Butea monosperma (Lamk.) Taub.	1.68	1.64	2.86	6.18	0.94	0.91	2.15	4.01
Cassia fistula L.	0.34	0.10	0.57	1.00	0.24	0.12	0.54	0.89
Chloroxylon swietenia DC	34.68	26.51	25.71	86.90	32.47	34.70	22.04	89.22
Cordia macleodii Hf.& Th.	NA	NA	NA	NA	NA	NA	NA	NA
Dalbergia paniculata Roxb.	NA	NA	NA	NA	NA	NA	NA	NA
Diospyros melanoxylon Roxb.	3.03	2.21	4.57	9.81	11.53	10.33	10.75	32.61
Flacourtia indica (Burm. f.) Merr.	0.67	1.44	1.14	3.26	1.18	1.28	2.15	4.60
Gardenia latifolia Ait.	1.01	0.57	1.14	2.72	2.35	3.08	2.15	7.59
Hardwickia binata Roxb.	7.41	10.00	9.71	27.12	2.35	2.28	4.84	9.48
Helicteres isora L.	0.34	0.15	0.57	1.06	NA	NA	NA	NA
Holarrhena antidysenterica Wall.	0.34	0.10	0.57	1.00	2.82	2.53	3.76	9.11
Holoptelia integrifolia (Roxb.) Planch.	NA	NA	NA	NA	NA	NA	NA	NA
Lagerstroemia parviflora Roxb.	1.01	0.57	1.71	3.30	2.12	1.84	4.30	8.26
Lannea coromandalica (Houtt.) Merr.	2.69	6.10	3.43	12.22	2.12	1.70	3.23	7.05
Madhuca indica Gmel.	4.71	6.47	2.86	14.04	1.18	1.16	2.15	4.49
Miliusa tomentosa (Roxb.) Sincl.	1.01	0.40	1.71	3.12	0.24	0.35	0.54	1.12
Manilkara hexandra (Roxb.) Dub.	NA	NA	NA	NA	NA	NA	NA	NA
Phyllanthus emblica L.	NA	NA	NA	NA	2.82	1.90	2.15	6.88
Pterocarpus marsupium Roxb.	NA	NA	NA	NA	0.47	0.22	0.54	1.23
Soymida febrifuga (Roxb.) Juss.	2.36	1.80	3.43	7.59	0.47	0.57	1.08	2.12
Sterculia urens Roxb.	NA	NA	NA	NA	NA	NA	NA	NA
Tectona grandis L.	14.81	19.65	12.57	47.04	16.94	16.15	12.37	45.46
Terminalia arjuna (Roxb. ex DC.) Wt. & Arn.	NA	NA	NA	NA	NA	NA	NA	NA
Terminalia bellerica (Gaertn.) Roxb.	0.34	0.24	0.57	1.14	NA	NA	NA	NA

Table 1 continued

Species	Standing trees				Tree sapling			
	Relative Density	Relative Dominance	Relative Frequency	IVI	Relative Density	Relative Dominance	Relative Frequency	IVI
Terminalia chebula Retz.	0.34	0.24	0.57	1.15	NA	NA	NA	NA
Terminalia tomentosa Wt. & Arn.	11.78	16.13	12.00	39.92	9.18	9.62	10.22	29.01
Zizyphus xylopyra (Retz.) Willd.	NA	NA	NA	NA	0.71	0.50	1.08	2.28

NA Not available

Terminalia tomentosa (IVI 29.01 and density 48 individuals/ha). A total of 35 tree species were found in the seedling stage in the PBR buffer zone (Tables 1, 2).

The density of tree seedlings varied across the tree species. *Terminalia tomentosa* had the highest density of seedlings (1472 individuals/ha), followed by C*hloroxylon swietenia* (571 individuals/ha), and *Diospyros melanoxylon* (465 individuals/ha), while the densities of *Bridelia retusa*, *Holoptelea integrifolia, Lannea coromandalica,* and *Sterculia urens* were equal (1 individuals/ha) and lowest among the 35 tree species available in seedling stage (Table 2).

Nine tree species and their saplings (e.g., *Albizzia procera, Azadirachta indica, Bridelia retusa, Cordia macleodii, Dalbergia paniculata, Holoptelia integrifolia, Manilkara hexandra, Sterculia urens,* and *Terminalia arjuna*) did not fall in the sampling plots and were sampled in the seedling stage only. *Aegle marmelos, Phyllanthus emblica,* and *Zizyphus xylopyra* were only found in sapling and seedling stages but not in the standing stage. *Albizzia odoratissima, Boswellia serrata, Helictrus isora, Terminalia bellerica* and *Terminalia chebula* were not found in the sapling and seeding stages.

Anthropogenic pressures

Anthropogenic pressures in terms of cut trees were highest on the C*hloroxylon swietenia*, with a density of 49 individuals/ha, followed by *Acacia catechu* (41 individuals/ha), and *Terminalia tomentosa* (23 individuals/ha). Out of 15 tree species facing biotic pressure due to cutting, four tree species had the lowest density (1 individuals/ha), including *Acacia leucophloea*, *Phyllanthus emblica*, *Madhuca indica,* and *Manilkara hexandra*. This shows that the biotic pressure was highest on C*hloroxylon swietenia.* There were 17 tree species with signs of lopping. C*hloroxylon swietenia* had the highest lopped tree density (32 individuals/ha), followed by *Tectona grandis* (21 individuals/ha). *Aegle marmelos*, *Phyllanthus emblica*, *Holarrhena antidysenterica, Lannea coromandelica* and *Madhuca indica* suffered less lopping (Table 2).

Discussion

The highest density and IVI of standing trees were observed in C*hloroxylon swietenia*, which indicates the predominance of this tree species in the present study areas. The density of cut (49 individuals/ha) and lopped (32 individuals/ha) trees of *Chloroxylon swietenia* was also highest. These figures gave an obvious picture of anthropogenic pressures on C*hloroxylon swietenia* indicating that the availability of this species was directly proportional to its extraction for house construction, agricultural tools, fuelwood, dye, and medicine.

Tectona grandis had the second highest density and IVI of standing trees, but the density of its lopped trees (21 individuals/ha) was higher than the cut trees (17 individuals/ha). This shows that the practice of lopping of branches was exercised more on *Tectona grandis* than cutting it as a whole. *Terminalia tomentosa*, the next tree species in hierarchy of standing trees density and IVI, was 32 % lopped and 8 % cut. Thus, there was a significant pressure on this plant species as the density of the cut trees was almost half of the density of standing trees. The low density of lopped trees depicts that the branches of this plant species do not have a substantial uses.

Hardwickia binata was the fourth dominant tree species in terms of its standing density (27 individuals/ha) and IVI (27.12). However, the condition of this tree species was marked as critical because the densities of cut trees (15 individuals/ha) and lopped trees (11 individuals/ha) were equally high. Its regeneration was also very poor as the density of saplings (12 individuals/ha) was much below the half of the standing trees, which indicates that the available standing trees may not bear the current pressure for long time. The status of *Acacia catechu* was far more surprising as the density of cut trees (41 individuals/ha) had overcome the density of standing trees (20 individuals/ha).

Madhuca indica could be considered in relatively better condition because the density of standing trees (17 individuals/ha) was higher as compared to the density of cut and lopped trees (one individuals/ha). One of the possible reasons for less cutting and lopping of *Madhuca indica* was

Table 2 Density per hectare of standing trees, their regeneration status in terms of density per hectare and anthropogenic pressures in the form of cut and lopped trees density per hectare in the Pachmarhi Biosphere Reserve of India

Species	Standing tree density	Regeneration		Anthropogenic pressure		Standing tree (%)	Cut tree (%)	Lopped tree (%)
		Sapling density	Seedling density	Cut tree density	Lopped tree density			
Acacia catechu Willd.	20	23	284	41	9	29	59	13
Acacia leucophloea Willd.	4	3	72	1	2	57	14	29
Aegle marmelos (L.) Corr.	NA[a]	1	32	NA	1	NA	NA	100
Adina cordifolia Hook f.	1	1	79	NA	NA	100	NA	NA
Albizzia odoratissima (L. f.) Benth.	1	NA	4	NA	NA	100	NA	NA
Albizzia procera (Roxb.) Benth.	NA	NA	10	NA	NA	NA	NA	NA
Anogeissus latifolia Bedd.	11	18	173	5	5	52	24	24
Azadirachta indica Juss.	NA	NA	4	NA	NA	NA	NA	NA
Bauhinia racemosa Lamk.	1	4	5	NA	NA	100	NA	NA
Boswellia serrata Colebr.	1	NA	NA	NA	NA	100	NA	NA
Bridelia retusa Spr.	NA	NA	1	NA	NA	NA	NA	NA
Buchanania lanzan Spr.	3	1	16	NA	NA	100	NA	NA
Butea monosperma (Lamk.) Taub.	6	5	112	NA	4	60	NA	40
Cassia fistula L.	1	1	9	NA	NA	100	NA	NA
Chloroxylon swietenia DC	126	168	571	49	32	61	24	15
Cordia macleodii Hf.& Th.	NA	NA	4	NA	NA	NA	NA	NA
Dalbergia paniculata Roxb.	NA	NA	5	NA	NA	NA	NA	NA
Diospyros melanoxylon Roxb.	11	60	465	10	10	35	32	32
Flacourtia indica (Burm. f.) Merr.	3	6	34	NA	2	60	NA	40
Gardenia latifolia Ait.	4	12	165	2	2	50	25	25
Hardwickia binata Roxb.	27	12	185	15	11	51	28	21
Helicteres isora L.	1	NA	NA	NA	NA	100	NA	NA
Holarrhena antidysenterica Wall.	1	15	216	4	1	17	67	17
Holoptelia integrifolia (Roxb.) Planch.	NA	NA	1	NA	NA	NA	NA	NA
Lagerstroemia parviflora Roxb.	4	11	84	NA	2	67	NA	33
Lannea coromandalica (Houtt.) Merr.	10	11	1	2	1	77	15	8
Madhuca indica Gmel.	17	6	20	1	1	89	5	5
Miliusa tomentosa (Roxb.) Sincl.	4	1	15	NA	NA	100	NA	NA
Manilkara hexandra (Roxb.) Dub.	NA	NA	9	1	NA	NA	100	NA
Phyllanthus emblica L.	NA	15	16	1	1	NA	50	50
Pterocarpus marsupium Roxb.	NA	2	7	NA	NA	NA	NA	NA
Soymida febrifuga (Roxb.) Juss.	9	2	70	NA	NA	100	NA	NA
Sterculia urens Roxb.	NA	NA	1	NA	NA	NA	NA	NA
Tectona grandis L.	54	88	132	17	21	59	18	23

Table 2 continued

Species	Standing tree density	Regeneration		Anthropogenic pressure		Standing tree (%)	Cut tree (%)	Lopped tree (%)
		Sapling density	Seedling density	Cut tree density	Lopped tree density			
Terminalia arjuna (Roxb. ex DC.) Wt. & Arn.	NA	NA	33	NA	NA	NA	NA	NA
Terminalia bellerica (Gaertn.) Roxb.	1	NA	NA	NA	NA	100	NA	NA
Terminalia chebula Retz.	1	NA	NA	NA	NA	100	NA	NA
Terminalia tomentosa Wt. & Arn.	43	48	1472	23	6	60	32	8
Zizyphus xylopyra (Retz.) Willd.	NA	4	50	2	NA	NA	100	NA

NA Not available

due to its multiple uses and its social and economical importance, as described by Kala (2011b). The density of standing trees of *Diospyros melanoxylon* was 11 individuals/ha with almost similar anthropogenic pressures in terms of cut and lopped (10 individuals/ha). This shows that the pressure on *Diospyros melanoxylon* was alarming and needs to be checked. The density of standing trees of *Gardenia latifolia* was quite a bit less (4 individuals/ha) with almost high anthropogenic pressures in terms of cutting and lopping (2 individuals/ha).

Nine tree species and their saplings, which include *Cordia macleodii, Sterculia urens,* and *Terminalia arjuna*, were so badly exploited that they were only found in seedlings stage. The unavailability of standing trees of 12 important tree species, including *Aegle marmelos* and *Phyllanthus emblica,* indicates the intensity and gravity of anthropogenic pressures on these tree species. Research on loss of species, especially *Aegle marmelos,* exists, which is associated with anthropogenic pressures in central Indian forests (Prasad et al. 2001).

Medicinally valuable tree species, such as *Boswellia serrata, Terminalia bellerica*, and *Terminalia chebula*, were not found in the sapling and seeding stages. The poor regeneration of these tree species may be due to excessive harvest and trampling of seedlings and saplings by cattle. There are similar reports on the impact of plant species by humans and cattle (Armesto and Pickett 1985; Mitchell and Kirby 1990; Rapport et al. 1998; Duchok et al. 2005). Locals frequently visited the forests for collection of edible fruits, fodder, fuelwood, medicinal plants, and to graze their cattle (Kala 2011a, 2013a). Cattle herders used to carry axes to cut and lop trees. In general, the forest seemed to be disturbed and fragmented in the study area due to severe anthropogenic pressures.

It is evident from the present study that many tree species are under severe pressure due to their over-exploitation. The forest structure and composition is also a result of traditional ecological knowledge created by human enterprises. If the present anthropogenic pressure continues, which has inhibited the regeneration of several tree species, then substantial negative ecological and societal consequences can be expected. It is possible to conserve the plant populations that have survived previous anthropogenic activities. Determining the potential for broad-scale, anthropogenic-related disturbances on tree species is therefore a key research priority for ecologists and conservationists, and is essential for supporting policy decisions and forest management practices.

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