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Structural attributes of lantana-invaded forest plots in Achanakmar–Amarkantak Biosphere Reserve, Central India

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Vegetation of lantana-invaded forest plots in the Achanakmar–Amarkantak Biosphere Reserve has been analysed. Only 20 out of the 126 plots examined were found infested with lantana (*Lantana camara* L.). These plots were divided into low lantana density and high lantana density groups. Ordination using Principal Component Analysis on the structural attributes of the vegetation separated the plots into low altitude and high altitude groups, but did not separate lower lantana density plots from higher lantana density plots. ANOVA also indicated no significant differences in the community-level structural attributes between lower and higher lantana density plots. Nevertheless, species-level differences were evident. Some species were more abundant and showed better regeneration potential in lower lantana density plots, while others did so in higher lantana density plots. However, time-series observations on permanent plots and experimental studies on competitive and allelopathic interactions in natural field plots are warranted for ascertaining the impact of lantana invasion and for ascribing the cause and effect relationships which, at present, remain speculative. Such studies will help identify and maintain ecological barriers to lantana invasion in order to promote conservation and biodiversity in the reserves.

Keywords: Achanakmar–Amarkantak Biosphere Reserve, biological invasion, invasive species, *Lantana camara*.

INVASIVE alien species threaten ecosystems, habitats or species with economic/environmental consequences[1]. Batianoff and Butler[2] have rated *Lantana camara* L., a native of tropical and subtropical America, among the highest ranked invasive species in Queensland, Australia. Also, it is among the world's 100 worst invasive alien species, as recognized by the Invasive Species Specialist Group[3,4]. Lantana is now found all over the Indian subcontinent, stretching from the sub-montane regions of the outer Himalaya to the southern most part of India[5,6]. In disturbed native forests, it has become the dominant understorey species, disrupting succession and decreasing biodiversity[7]. Lantana has the potential to block succession and displace native species, resulting in a reduction in biodiversity[8], particularly because of its extreme inflammability and growing anthropogenic disturbances, including fire[9]. Not only in natural forests but also in protected areas, lantana invasion is considered a major threat to native plants and animals. For example, it has invaded and proliferated in the Corbett Tiger Reserve, Kalesar National Park and Pachmarhi Biosphere Reserve, resulting in loss of biodiversity and many ecological functions[10]. In contrast, there are studies which suggest that lantana may not suppress the growth of native species[11] and that there are no clear-cut patterns to indicate a significant impact of lantana on forest structure and composition[6].

This communication compares the structural attributes of vegetation in plots with differential intensity of lantana invasion in the Achanakmar–Amarkantak Biosphere Reserve, Central India, in order to examine whether or not the differential intensity of lantana invasion is associated with changes in structural attributes of forest vegetation.

The study was carried out in the above-mentioned Biosphere Reserve (notified by the Government of India on 30 March 2005), located between lat. 22°15′–22°58′N and long. 81°25′–82°5′E, with Achanakmar Wildlife Sanctuary as the core area (Figure 1). The area experiences typical monsoon climate, with three distinct seasons – summer from March to June, rainy season from July to October, and winter from November to February. More than 85% of the annual average rainfall is received during the monsoon months. The mean annual rainfall for Amarkantak (1070 m) is about 1620 mm, distributed over 92 rainy days. Mean daily minimum temperature reaches 1.34°C in January and mean daily maximum temperature about 33.9°C in May. The annual rainfall at a low-altitude site,

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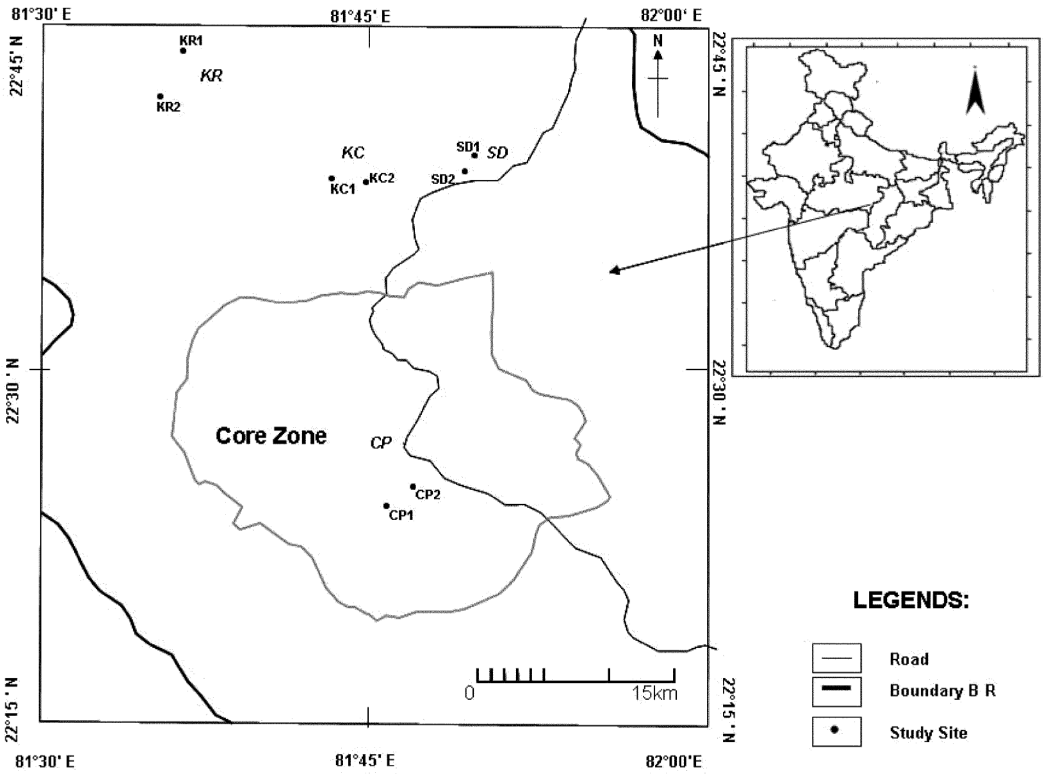

Figure 1. Location of lantana-invaded study sites in the Achanakmar–Amarkantak Biosphere Reserve, Central India. CP, Chaparwa (CP1, CP2); KC, Kabirchabutra (KC1, KC2), KR, Karanjia (KR1, KR2) and SD, Sambhudhara (SD1, SD2).

viz. Pendra (625 m) averages 1382.6 mm, distributed over 76 rainy days, and mean daily temperature ranges from 10.9°C (January) to 39.1°C (May). The forest is seasonally dry tropical with Northern Tropical Moist Deciduous Forest[12] predominating.

The vegetation was sampled from 42 sites by laying, at each site, three randomly selected circular plots [each 10 m radius for enumerating trees (≥9.6 cm dbh), 2 m radius for shrubs (including lantana), saplings (≥3.2 cm and <9.6 cm dbh) and established tree seedlings/sprouts (≥30 cm height and <3.2 cm diameter)]. Herbs were enumerated in 1 sq. m quadrats. The 2 m radius plots and 1 sq. m quadrats were nested within 10 m radius plots. Diameter at breast height for trees and saplings, and 10 cm above the ground for seedlings, was recorded for each individual. In the case of herbs, only number of individuals was counted. The altitude of each plot was recorded using an altimeter.

For quantifying the disturbance regime, we adapted the method used by Kumar and Shahabuddin[13] for Sariska Tiger Reserve, India. In brief, four distinct disturbance indicators were recorded for each sampling plot: the proportion of trees showing signs of lopping, scale of lopping (on a scale of 0–4 for each tree: 0, no lopping; 1, rudimentary signs of lopping; 2, up to half of the main branches lopped; 3, more than half of the main branches lopped, and 4, tree reduced to a stump by lopping or harvesting; the total lopping score was then divided by the total number of trees present), total number of dung piles of livestock, and number of separate foot-trails.

Among the 126 plots (distributed over 42 sites), only 20 (distributed over eight sites) had *L. camara*. These plots were divided into two groups, with <5000 and >5000 individuals of lantana. This communication summarizes vegetation analysis of the lantana-invaded plots of the Reserve.

Data on tree and shrub vegetation were quantitatively analysed for density and basal area[14]. For herbs, only density was calculated. Species richness (SR) as an index of diversity was calculated following Menhinick[15]. The plots were ordinated by Principal Component Analysis (PCA) option in Biodiversity Pro, ver. (2) software[16], using density and basal area for trees (including saplings and seedlings) and shrubs, density for herbs and number of species and species richness of all growth forms. The relationships of PCA axes with altitude and disturbance intensity were determined. One-way ANOVA was used to detect differences in the mean values of structural attributes. All statistical analyses were done using SPSS statistical software package[17].

We expected that if structural attributes of vegetation are affected by the intensity of lantana invasion, then PCA ordination would separate plots with lower lantana density from those with higher lantana density. PCA ordination of all lantana-invaded plots ($n = 20$) did separate the plots into two groups, but each group had both lower lantana as well as higher lantana density plots (Figure 2 *a*). PCA axis-1 was significantly related with altitude (Table 1). Thus the ordination only separated low altitude plots ($n = 10$), from the relatively higher altitude plots ($n = 10$), but not the lower lantana density plots from higher lantana density plots. Plots in the top left quarter of the ordination space averaged 682 m in altitude and those in the right quarter, 1036 m. When lower lantana density plots were subjected to PCA, low altitude plots in the top right quarter ($n = 7$) were separated from high altitude plots in the top left quarter ($n = 5$; Figure 2 *b*). Similarly, the higher lantana density plots were separated into a low altitude group in the bottom left quarter ($n = 3$) and a higher altitude group in the bottom right quarter ($n = 5$) of the ordination space (Figure 2 *c*). PCA axis-1 in the above two ordinations also was significantly related to altitude (Table 1).

The structural attributes of all the four groups (viz. lower lantana density, low and high altitude, and higher lantana density, low and high altitude) are summarized in Table 2. ANOVA indicated that several structural attributes of lower lantana density, low altitude plots significantly differed from lower lantana density, high altitude plots, and those of higher lantana density, low altitude plots from higher lantana density, high altitude plots (see *F* ratios in Table 2). High altitude plots with lower lantana density had higher shrub and herb density, higher tree basal area, but lower sapling and seedling density, lower sapling and seedling basal area, lower number of tree species per plot and lower number of seedling species compared to low altitude plots having lower lantana density. Higher lantana density, high altitude plots had lower sapling and seedling density, lower sapling and seedling basal area and smaller number of sapling and seedling species compared to higher lantana density, low altitude plots. On the other hand, there were no significant differences between lower lantana density, low altitude plots and higher lantana density, low altitude plots. Similarly, structural attributes of lower lantana density, high altitude plots were not significantly different from higher lantana density, high altitude plots (*F* ratios not shown). Although low and high altitude lantana-invaded plots differed from each other in several structural attributes, the differences were not due to lantana density. In contrast to the above observation, Murali and Setty[11] found higher species richness and stem density of tree and shrub layers in plots infested with lantana compared to those without lantana in B.R. Hills Temple Wildlife Sanctuary, Karnataka, and Aravind *et al.*[6] reported a decrease in tree basal area and an increase in species richness of tree seedlings with an increase in lantana density in Male Mahadeshwara Hills Reserve Forest, Karnataka. The species richness of dry rainforest in North Queensland is reported to decline as the density of lantana increases, but the saplings and seedlings had comparable densities in heavy and light lantana invasions[18]. Both the number of species and the number of individuals were lower in plots with high lantana cover than those with low lantana cover in Vindhyan dry deciduous forest[19].

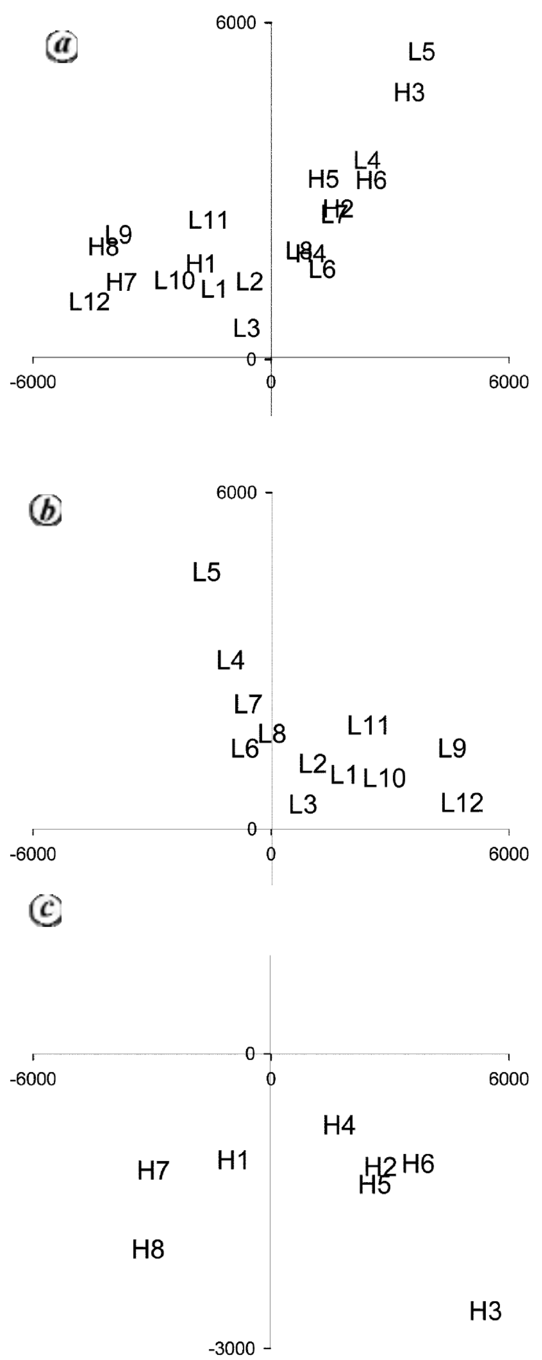

Figure 2. PCA ordination of lantana-invaded plots in Achanakmar–Amarkantak Biosphere Reserve. ***a***, All plots. ***b***, Plots with lower lantana density. ***c***, Plots with higher lantana density. L_1–L_{12}, Lower lantana density plots; and H_1–H_8, Higher lantana density plots. Location of these plots with reference to Figure 1 are: KR1 (L_1, L_2, H_1), KR2 (L_3), KC1 (L_4, L_5), KC2 (L_6, H_2, H_3), SD1 (H_4–H_6), SD2 (L_7, L_8), CP1 (L_9–L_{11}) and CP2 (L_{12}, H_7, H_8).

Table 1. Pearson correlation coefficients among PCA axes, altitude and disturbance variables for lantana-invaded forest plots in Achanakmar–Amarkantak Biosphere Reserve

First variable	Second variable	All plots (n = 20)	Lower lantana density (n = 12)	Higher lantana density (n = 8)
Altitude	PC axis 1	0.851**	0.828**	0.888**
	PC axis 2	0.358^{NS}	0.238^{NS}	0.544^{NS}
	% tree lopped	-0.030^{NS}	0.048^{NS}	-0.217^{NS}
	Scale of lopping	0.262^{NS}	0.275^{NS}	0.186^{NS}
	No. of dung piles	–0.215	-0.021^{NS}	-0.579^{NS}
	No. of trails	–0.038	-0.041^{NS}	-0.125^{NS}
PC axis 1	PC axis 2	0.709**	0.668*	0.797*
	% tree lopped	-0.113^{NS}	0.057^{NS}	-0.378^{NS}
	Scale of lopping	0.126^{NS}	0.229^{NS}	-0.034^{NS}
	No. of dung piles	-0.293^{NS}	-0.027^{NS}	–0.713*
	No. of trails	-0.177^{NS}	-0.078^{NS}	-0.361^{NS}
PC axis 2	% tree lopped	-0.274^{NS}	-0.285^{NS}	-0.400^{NS}
	Scale of lopping	-0.134^{NS}	-0.236^{NS}	-0.169^{NS}
	No. of dung piles	-0.382^{NS}	-0.300^{NS}	-0.597^{NS}
	No. of trails	-0.281^{NS}	-0.314^{NS}	-0.418^{NS}
Per cent tree lopped	Scale of lopping	0.914**	0.926**	0.907**
	No. of dung piles	0.680**	0.593*	0.851**
	No. of trails	0.887**	0.857**	0.918**
Scale of lopping	No. of dung piles	0.489*	0.410^{NS}	0.653^{NS}
	No. of trails	0.826*	0.732**	0.903**
No. of dung piles	No. of trails	0.735*	0.679*	0.878**

**Significant at $P < 0.01$; *Significant at $P < 0.05$; ^{NS}Not significant.

However, causality cannot be inferred from the above one-time field studies. Anthropogenic disturbance is considered an important factor for lantana proliferation (see Sharma *et al.*[7] and Hiremath and Sundaram[9] for review). In our study also, higher values of the disturbance variables were associated with higher lantana density (Table 2).

Since we found no significant differences in structural attributes of vegetation at community level due to differential intensity of lantana infestation, we looked for the response of individual species (Table 3). At low altitudes, in plots with lower lantana density, the density of adult trees of *Grewia tiliifolia*, *Terminalia tomentosa* and *Woodfordia fruticosa* was higher compared to higher lantana density plots. Also, in these plots, density of saplings of *Butea monosperma* and *Grewia tiliifolia*, and seedling density of *Diospyros melanoxylon*, *Grewia tiliifolia*, *Lagerstroemia parviflora* and *Zizyphus mauritiana* were higher. Among shrubs, density of *Lawsonia* sp., *Phoenix acaulis* and *Sida cordifolia*, and among herbs, that of *Ageratum conyzoides*, *Bidens biternata*, *Canscora diffusa*, *Desmodium triflorum*, *Elephantopus scaber* and *Sida acuta* was higher in lower lantana density plots compared to higher lantana density plots. On the other hand, in plots with higher lantana density, the density of adult trees of *Acacia nilotica*, *A. senegal*, *Anogeissus latifolia*, *B. monosperma*, *D. melanoxylon* and *Ougeinia oojeinsis* was higher compared to the lower lantana density plots. Also, in these plots, density of both saplings and seedlings of *Mallotus philippensis*, *Phyllanthus emblica* and *Woodfordia fruticosa*, and among shrubs and herbs, density of *Carissa spinarum*, *Flemingea bracteata*, *Chlorophytum tuberosum*, *Curculigo orchioides*, *Dioscorea bulbifera*, *Hemidesmus indicus* and *Ipomoea hederifolia* was higher compared to lower lantana density plots.

At high altitude, plots with lower lantana density had higher density of adult individuals of *Adina cordifolia*, *Cassia fistula*, *O. oojeinsis*, *P. emblica*, *Syzygium cumini* and *Terminalia tomentosa* compared to higher lantana density plots. Also, these plots had higher density of *S. cumini* and *C. fistula* saplings, higher density of *Cassia occidentalis*, *F. bracteata*, *Flemingea strobilifera*, *Adiantum incisum*, *Ageratum conyzoides*, *Boehmeria benghalense*, *Eupatorium odoratum*, *Plectranthus mollis* and *Tectaria polymorpha* compared to higher lantana density plots. In contrast, plots with higher lantana density had higher density of adult individuals of *Buchanania lanzan* and *Semecarpus anacardium* compared to lower lantana density plots. Also, these plots had higher density of *Mallotus philippensis* and *Shorea robusta* saplings, higher density of *Flemingea macrophylla, B. biternata, C. diffusa, Dioscorea bulbifera*, *Dryopteris cochleata* and *E. scaber* compared to lower lantana density plots.

Table 2. Selected structural attributes and disturbance regime of lantana-invaded forest plots in Achanakmar–Amarkantak Biosphere Reserve

	Lower lantana density			Higher lantana density		
Structural attribute	Low altitude (mean = 701 m) (*n* = 7)	High altitude (mean = 1029 m) (*n* = 5)	$F_{1,11}$	Low altitude (mean = 663 m) (*n* = 3)	High altitude (mean = 1044 m) (*n* = 5)	$F_{1,7}$
Density (ha^{-1})						
Tree	869	898	0.065^{NS}	881	987	0.378^{NS}
Sapling	2456	363	4.778*	4850	522	20.934**
Seedling	7846	1273	13.615**	9551	1274	29.534**
Shrub	9096	18,784	4.984*	10,612	19,421	4.335^{NS}
Density (sq. m)						
Herb	40	47	154.821*	32	39.8	1.229^{NS}
Basal area (sq. m/ha)						
Tree	15.40	30.44	8.897*	17.74	30.14	2.616^{NS}
Sapling	2.17	0.28	5.318*	4.84	0.86	9.458*
Seedling	3.07	0.47	20.541***	3.74	0.47	52.580***
Shrub	2.97	4.19	1.124^{NS}	3.22	3.92	0.222^{NS}
No. of species per plot[a]						
Tree	7.29	4.20	5.758*	6.33	3.40	2.110^{NS}
Sapling	2.43	0.80	4.178^{NS}	4.33	0.80	40.514***
Seedling	2.71	0.80	10.688*	3.33	0.80	13.207*
Shrub	3.43	3.20	0.152^{NS}	3.67	3.00	0.395^{NS}
Herb	10.86	10.04	0.610^{NS}	10.67	9.20	0.682^{NS}
Species richness						
Tree	1.42	0.83	5.157*	1.20	0.68	1.386^{NS}
Sapling	1.81	0.75	1.984^{NS}	1.95	1.45	0.396^{NS}
Seedling	0.82	0.57	1.911^{NS}	0.96	0.52	2.184^{NS}
Shrub	0.96	0.72	1.345^{NS}	1.02	0.61	3.756^{NS}
Herb	1.74	1.52	1.695^{NS}	1.70	1.45	1.419^{NS}
Disturbance regime						
Per cent tree lopped	13.24	13.04	0.001^{NS}	22.70	14.13	1.106^{NS}
Scale of lopping	0.18	0.24	0.265^{NS}	0.36	0.3	0.022^{NS}
No. of dung piles	4.14	3.40	0.155^{NS}	6.33	2.60	5.627*
No. of trails	1.71	1.20	0.381^{NS}	3.00	1.80	1.095^{NS}

***Significant at $P < 0.001$; **Significant at $P < 0.01$; *Significant at $P < 0.05$; ^{NS}Not significant.
[a]314 sq. m for trees, 12.56 sq. m for saplings, seedlings and shrubs, and 1 sq. m for herbs.

Evidently, differences at species level do occur in plots with differential intensity of lantana invasion; some species have greater abundance in lower lantana density plots while a few exhibit greater abundance in higher lantana density plots. It is possible that some trees facilitate proliferation of lantana by acting as preferred perching habitat for birds, and others restrict population growth of lantana by casting dense shade or through competitive interaction. Frugivorous birds are important dispersal agents for lantana[7] and shading is a strong limiting factor for its proliferation[20]. However, scientifically sound inference can be drawn only through experimental studies.

Field studies indicate that lantana could suppress regeneration potential of native species[21–23], but this effect appears to be selective. Aravind *et al.*[6] found that in moist deciduous forests, there was significant increase in species richness of seedlings with increase in lantana density, but seedlings of eight dominant species showed a decline. In the present study, seedlings of some species (e.g. *Grewia tiliifolia*, *D. melanoxylon*, *L. parviflora* and *Z. mauritiana*) were conspicuously suppressed in plots with higher lantana density, while those of certain other species (e.g. *B. monosperma*, *M. philippensis*, *P. emblica* and *W. fruticosa*) were more numerous in higher density lantana plots (Table 3). Similarly, while some shrub and herb elements were encouraged by high lantana density, certain others were suppressed. The suppressive effect could be due to competitive interaction together with allelopathy[7,24]. Higher lantana density may provide protection from grazing to seedlings and juveniles in some cases.

In conclusion, this study has revealed that while so far in the Achanakmar–Amarkantak Biosphere Reserve, under

Table 3. Species whose abundance is substantially higher or lower in higher lantana density plots compared to lower lantana density plots in respective altitude zones (values are mean number of individuals per sq. m for herbs and per ha for all others)

	Low altitude		High altitude	
Species	Lower lantana density (*n* = 7)	Higher lantana density (*n* = 3)	Lower lantana density (*n* = 5)	Higher lantana density (*n* = 5)
Tree				
Acacia nilotica	4.6	21.3	–	–
A. senegal	9.1	31.9	–	–
Adina cordifolia	–	–	19.1	12.7
Anogeissus latifolia	109.0	127.4	6.4	0.0
Buchanania lanzan	–	–	0.0	25.5
Butea monosperma	91.0	127.4	–	–
Cassia fistula	9.1	10.6	25.5	12.7
Grewia tiliifolia	45.5	21.3	–	–
Diospyros melanoxylon	36.4	95.6	–	–
Ougeinia oojeinsis	9.1	21.2	44.6	19.1
Phyllanthus emblica	18.2	0.0	12.7	0.0
Semecarpus anacardium	–	–	0.0	25.5
Syzygium cumini	–	–	25.5	0.0
Terminalia tomentosa	41.0	21.2	25.5	12.7
Woodfordia fruticosa	36.4	0.0	–	–
Sapling				
Butea monosperma	573.1	541.2	–	–
C. fistula	–	–	165.6	159.2
D. melanoxylon	609.5	838.4	–	–
Grewia tiliifolia	227.4	0.0	–	–
Mallotus philippensis	227.4	795.9	12.7	318.4
P. emblica	22.7	286.5	–	–
S. cumini	–	–	159.2	0.0
Shorea robusta	227.4	1061.2	25.5	44.6
W. fruticosa	341.1	1061.2	–	–
Seedling				
B. monosperma	1933.0	2653.1	–	–
D. melanoxylon	909.6	265.3	–	–
G. tiliifolia	454.8	0.0	–	–
M. philippensis	0.0	530.6	–	–
P. emblica	0.0	795.9	–	–
Lagerstroemia parviflora	113.7	0.0	–	–
W. fruticosa	2387.8	3183.7	–	–
Zizyphus mauritiana	227.4	0.0	–	–
Shrub				
Carissa spinarum	1591.9	2653.1	–	–
Cassia occidentalis	–	–	318.4	0.0
Flemingea bracteata	568.5	795.9	318.4	0.0
Flemingea macrophylla	–	–	0.0	795.9
Flemingea strobilifera	–	–	6845.0	3183.9
Lantana camara	3865.9	5571.5	3979.7	8118.5
Lawsonia sp.	568.5	0.0	–	–
Phoenix acaulis	1137.1	530.6	–	–
Sida cordifolia	341.1	0.0	–	–
Herb				
Adiantum incisum	–	–	3.2	0.0
Ageratum conyzoides	4.6	0.0	7.4	5.0
Bidens biternata	2.4	1.0	0.6	1.8
Boehmeria macrophylla	–	–	2.8	1.2
Canscora diffusa	1.3	0.0	2.8	3.6
Chlorophytum tuberosum	0.7	3.3	–	–
Curculigo orchioides	1.4	3.7	–	–
Desmodium triflorum	4.4	1.7	2.6	2.6
Dioscorea bulbifera	0.3	1.3	1.2	2.0
Dryopteris cochleata	–	–	0.0	2.0
Elephantopus scaber	5.3	3.7	1.0	2.4
Eupatorium odoratum	–	–	2.6	0.6
Hemidesmus indicus	0.1	1.3	–	–
Ipomoea hederifolia	0.4	2.3	–	–
Plectranthus mollis	2.9	0.0	4.2	2.8
Pogostemon benghalense	–	–	1.8	0.8
Sida acuta	2.4	0.7	0.4	0.0
Tectaria polymorpha	–	–	2.0	0.0

–, Species altogether absent in low/high altitude plots.

the present disturbance regime, there has been no adverse effect of lantana invasion on structural attributes of vegetation at community level, the effect can potentially build up with time, particularly at species level. Since proliferation of lantana may increase fuel-load, suppress regeneration potential of some species, and its allelochemicals might be deleterious for the herbivorous wildlife, management strategies to reduce weed encroachment and community degradation are called for, especially as only parts of the Reserve are currently affected. Lantana may be favoured by disturbances such as fire and grazing[9,25] and by canopy disturbance, permitting greater light availability[20]. Therefore, steps are needed to check livestock-grazing and tree-lopping. However, time-series observations on permanent plots and experimental studies on competitive interactions and allelopathy in natural field plots are warranted for ascertaining the impact of lantana invasion and for ascribing cause and effect relationship which, at present, are only speculative. Such studies will help identify and maintain ecological barriers to lantana invasion in order to promote conservation and biodiversity in the reserves.

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