

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

P. K. Sahu<sup>1</sup> and J. S. Singh<sup>2,\*</sup>

<sup>1</sup>Botanical Survey of India, Central Circle, Allahabad 211 002, India

<sup>2</sup>Department of Botany, Banaras Hindu University, Varanasi 221 005, India

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.

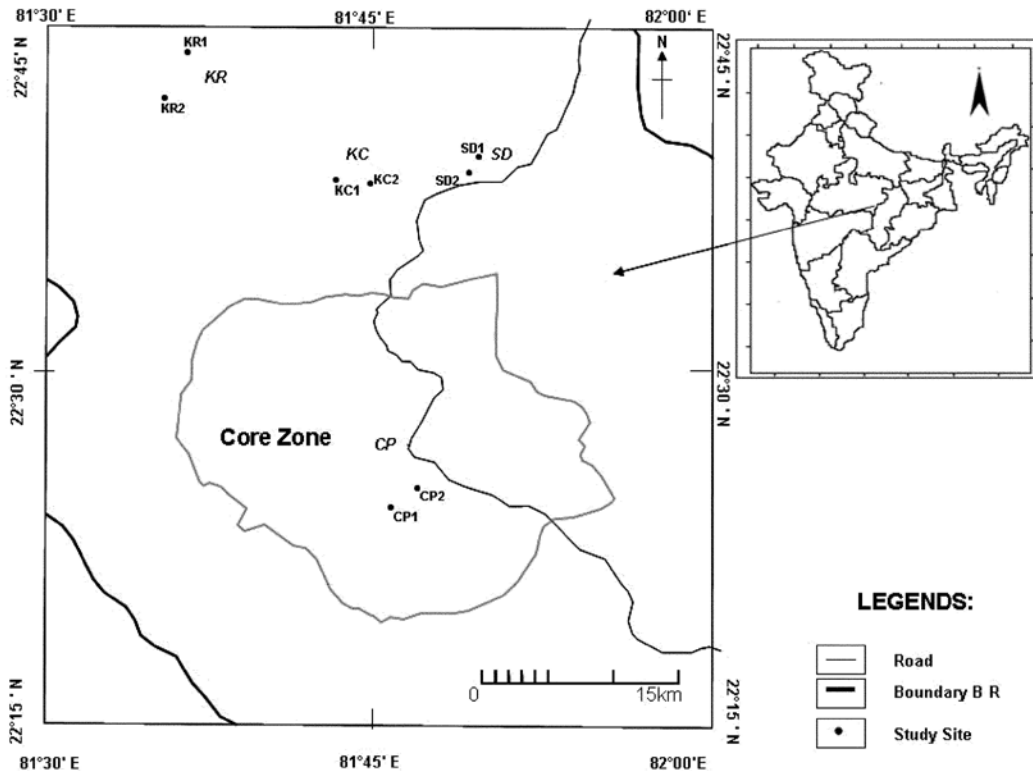
**Keywords:** Achanakmar–Amarkantak Biosphere Reserve, biological invasion, invasive species, *Lantana camara*.

INVASIVE alien species threaten ecosystems, habitats or species with economic/environmental consequences<sup>1</sup>. Batiannoff and Butler<sup>2</sup> 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<sup>3,4</sup>. Lantana is now found all over the Indian sub-continent, stretching from the sub-montane regions of the outer Himalaya to the southern most part of India<sup>5,6</sup>. In disturbed native forests, it has become the dominant understorey species, disrupting succession and decreasing biodiversity<sup>7</sup>. Lantana has the potential to block succession and displace native species, resulting in a reduction in biodiversity<sup>8</sup>, particularly because of its extreme inflammability and growing anthropogenic disturbances, including fire<sup>9</sup>. 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<sup>10</sup>. In contrast, there are studies which suggest that lantana may not suppress the growth of native species<sup>11</sup> and that there are no clear-cut patterns to indicate a significant impact of lantana on forest structure and composition<sup>6</sup>.

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,

\*For correspondence. (e-mail: singh.js1@gmail.com)



**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<sup>12</sup> 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 ( $\geq 9.6$  cm dbh), 2 m radius for shrubs (including lantana), saplings ( $\geq 3.2$  cm and  $< 9.6$  cm dbh) and established tree seedlings/sprouts ( $\geq 30$  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<sup>13</sup> 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 har-

vesting; 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<sup>14</sup>. For herbs, only density was calculated. Species richness (SR) as an index of diversity was calculated following Menhinick<sup>15</sup>. The plots were ordinated by Principal Component Analysis (PCA) option in Biodiversity Pro, ver. (2) software<sup>16</sup>, 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<sup>17</sup>.

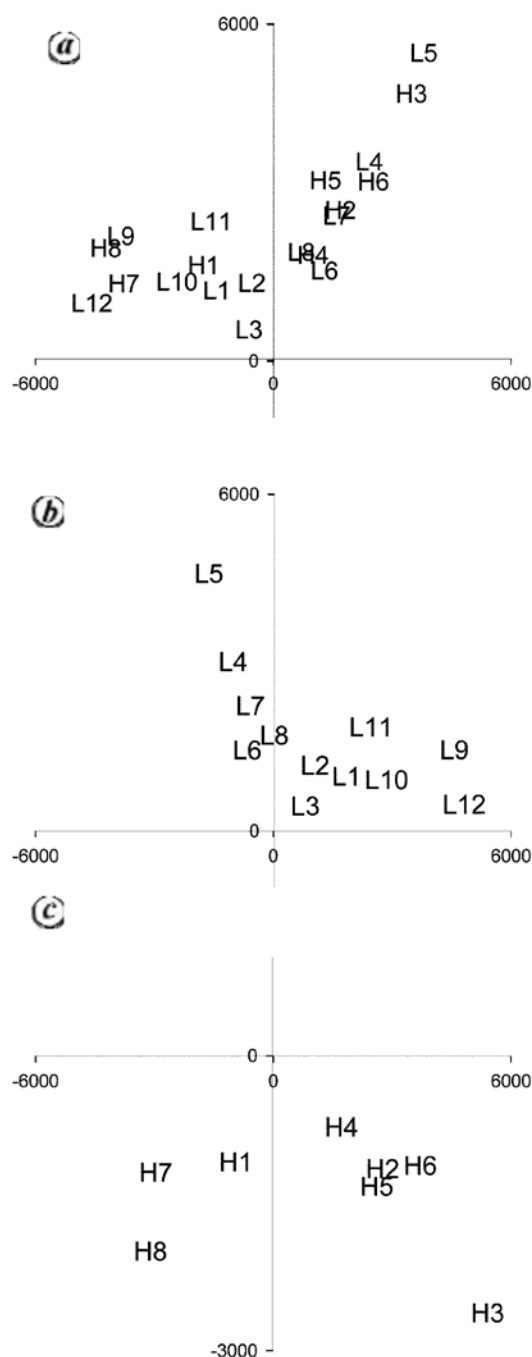
We expected that if structural attributes of vegetation are affected by the intensity of lantana invasion, then PCA ordination would separate plots with lower lantana

## RESEARCH COMMUNICATIONS

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 2a). 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 2b). 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 2c). 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<sup>11</sup> 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.*<sup>6</sup> 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 lan-

tana increases, but the saplings and seedlings had comparable densities in heavy and light lantana invasions<sup>18</sup>. 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 Vindhyana dry deciduous forest<sup>19</sup>.



**Figure 2.** PCA ordination of lantana-invaded plots in Achanakmar-Amargantak 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 <sup>NS</sup>  | 0.238 <sup>NS</sup>            | 0.544 <sup>NS</sup>            |
|                      | % tree lopped     | -0.030 <sup>NS</sup> | 0.048 <sup>NS</sup>            | -0.217 <sup>NS</sup>           |
|                      | Scale of lopping  | 0.262 <sup>NS</sup>  | 0.275 <sup>NS</sup>            | 0.186 <sup>NS</sup>            |
|                      | No. of dung piles | -0.215               | -0.021 <sup>NS</sup>           | -0.579 <sup>NS</sup>           |
|                      | No. of trails     | -0.038               | -0.041 <sup>NS</sup>           | -0.125 <sup>NS</sup>           |
| PC axis 1            | PC axis 2         | 0.709**              | 0.668*                         | 0.797*                         |
|                      | % tree lopped     | -0.113 <sup>NS</sup> | 0.057 <sup>NS</sup>            | -0.378 <sup>NS</sup>           |
|                      | Scale of lopping  | 0.126 <sup>NS</sup>  | 0.229 <sup>NS</sup>            | -0.034 <sup>NS</sup>           |
|                      | No. of dung piles | -0.293 <sup>NS</sup> | -0.027 <sup>NS</sup>           | -0.713*                        |
|                      | No. of trails     | -0.177 <sup>NS</sup> | -0.078 <sup>NS</sup>           | -0.361 <sup>NS</sup>           |
| PC axis 2            | % tree lopped     | -0.274 <sup>NS</sup> | -0.285 <sup>NS</sup>           | -0.400 <sup>NS</sup>           |
|                      | Scale of lopping  | -0.134 <sup>NS</sup> | -0.236 <sup>NS</sup>           | -0.169 <sup>NS</sup>           |
|                      | No. of dung piles | -0.382 <sup>NS</sup> | -0.300 <sup>NS</sup>           | -0.597 <sup>NS</sup>           |
|                      | No. of trails     | -0.281 <sup>NS</sup> | -0.314 <sup>NS</sup>           | -0.418 <sup>NS</sup>           |
| 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 <sup>NS</sup>            | 0.653 <sup>NS</sup>            |
|                      | 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  $P < 0.05$ ; <sup>NS</sup>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.*<sup>7</sup> and Hiremath and Sundaram<sup>9</sup> 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 com-

pared 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 orchoides*, *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*, *Flemingia 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 *Flemingia macrophylla*, *B. biternata*, *C. diffusa*, *Dioscorea bulbifera*, *Dryopteris cochleata* and *E. scaber* compared to lower lantana density plots.

## RESEARCH COMMUNICATIONS

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

| Structural attribute                 | Lower lantana density                     |   | $F_{1,11}$          | Higher lantana density                    |   | $F_{1,7}$           |
|--------------------------------------|---|---|---------------------|---|---|---------------------|
|                                      | Low altitude<br>(mean = 701 m)<br>(n = 7) | High altitude<br>(mean = 1029 m)<br>(n = 5) |                     | Low altitude<br>(mean = 663 m)<br>(n = 3) | High altitude<br>(mean = 1044 m)<br>(n = 5) |                     |
| Density (ha <sup>-1</sup> )          |   |   |                     |   |   |                     |
| Tree                                 | 869                                       | 898   | 0.065 <sup>NS</sup> | 881                                       | 987   | 0.378 <sup>NS</sup> |
| 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 <sup>NS</sup> |
| Density (sq. m)                      |   |   |                     |   |   |                     |
| Herb                                 | 40  | 47  | 154.821*            | 32  | 39.8  | 1.229 <sup>NS</sup> |
| Basal area (sq. m/ha)                |   |   |                     |   |   |                     |
| Tree                                 | 15.40                                     | 30.44                                       | 8.897*              | 17.74                                     | 30.14                                       | 2.616 <sup>NS</sup> |
| 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 <sup>NS</sup> | 3.22                                      | 3.92  | 0.222 <sup>NS</sup> |
| No. of species per plot <sup>a</sup> |   |   |                     |   |   |                     |
| Tree                                 | 7.29                                      | 4.20  | 5.758*              | 6.33                                      | 3.40  | 2.110 <sup>NS</sup> |
| Sapling                              | 2.43                                      | 0.80  | 4.178 <sup>NS</sup> | 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 <sup>NS</sup> | 3.67                                      | 3.00  | 0.395 <sup>NS</sup> |
| Herb                                 | 10.86                                     | 10.04                                       | 0.610 <sup>NS</sup> | 10.67                                     | 9.20  | 0.682 <sup>NS</sup> |
| Species richness                     |   |   |                     |   |   |                     |
| Tree                                 | 1.42                                      | 0.83  | 5.157*              | 1.20                                      | 0.68  | 1.386 <sup>NS</sup> |
| Sapling                              | 1.81                                      | 0.75  | 1.984 <sup>NS</sup> | 1.95                                      | 1.45  | 0.396 <sup>NS</sup> |
| Seedling                             | 0.82                                      | 0.57  | 1.911 <sup>NS</sup> | 0.96                                      | 0.52  | 2.184 <sup>NS</sup> |
| Shrub                                | 0.96                                      | 0.72  | 1.345 <sup>NS</sup> | 1.02                                      | 0.61  | 3.756 <sup>NS</sup> |
| Herb                                 | 1.74                                      | 1.52  | 1.695 <sup>NS</sup> | 1.70                                      | 1.45  | 1.419 <sup>NS</sup> |
| Disturbance regime                   |   |   |                     |   |   |                     |
| Per cent tree lopped                 | 13.24                                     | 13.04                                       | 0.001 <sup>NS</sup> | 22.70                                     | 14.13                                       | 1.106 <sup>NS</sup> |
| Scale of lopping                     | 0.18                                      | 0.24  | 0.265 <sup>NS</sup> | 0.36                                      | 0.3   | 0.022 <sup>NS</sup> |
| No. of dung piles                    | 4.14                                      | 3.40  | 0.155 <sup>NS</sup> | 6.33                                      | 2.60  | 5.627*              |
| No. of trails                        | 1.71                                      | 1.20  | 0.381 <sup>NS</sup> | 3.00                                      | 1.80  | 1.095 <sup>NS</sup> |

\*\*\*Significant at  $P < 0.001$ ; \*\*Significant at  $P < 0.01$ ; \*Significant at  $P < 0.05$ ; <sup>NS</sup>Not significant.

<sup>a</sup>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<sup>7</sup> and shading is a strong limiting factor for its proliferation<sup>20</sup>. However, scientifically sound inference can be drawn only through experimental studies.

Field studies indicate that lantana could suppress regeneration potential of native species<sup>21–23</sup>, but this effect appears to be selective. Aravind *et al.*<sup>6</sup> 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<sup>7,24</sup>. 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)

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

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

## RESEARCH COMMUNICATIONS

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<sup>9,25</sup> and by canopy disturbance, permitting greater light availability<sup>20</sup>. 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.

1. GISP, Global strategy on invasive alien species. Global Invasive Species Programme Workshop, September 2000, Cape Town, South Africa, 2001.
2. Batianoff, G. N. and Butler, D. W., Impact assessment and analysis of sixty-six priority invasive weeds in southeast Queensland. *Plant Prot. Q.*, 2003, **18**, 11–17.
3. Invasive Species Specialist Group, IUCN, 100 world's worst invasive alien species, 2001; available at <http://www.issg.org/booklet.pdf>
4. Lowe, S., Browne, M., Boudjelas, S. and De Poorter, M., Hundred of the world's worst invasive alien species: A selection from the Global Invasive Species Database. Invasive Species Specialist Group of the IUCN–World Conservation Union, 2004; <http://www.issg.org/booklet.pdf>
5. Thakur, M. L., Ahmad, M. and Thakur, R. K., Lantana weed (*Lantana camara* var. *aculeata* Linn.) and its possible management through natural insect pests in India. *Indian For.*, 1992, **118**, 467–488.
6. Aravind, N. A., Rao, D., Vanaraj, G., Uma Shaanker, R., Ganeshaiyah, K. N. and Poulsen, J. G., Impact of *Lantana camara* invasion on plant communities in Male Mahadeshwara Hills Reserve Forest, South India. In Proceedings on Invasive Alien Species and Biodiversity in India (eds Rai, L. C. and Gour, J. P.), Department of Botany, Banaras Hindu University, Varanasi, 2006, pp. 1–12.
7. Sharma, G. P., Raghubanshi, A. K. and Singh, J. S., *Lantana* invasion: An overview. *Weed Biol. Manage.*, 2005, **5**, 157–165.
8. Day, M. D., Wiley, C. J., Playford, J. and Zaluvki, M. P., *Lantana*: Current management status and future prospects. ACIAR Monogr., Canberra, 2003, p. 102.
9. Hiremath, A. J. and Sundaram, B., The fire–lantana cycle hypothesis in Indian forests. *Conserv. Soc.*, 2005, **3**, 26–42.
10. Babu, C. R., Annual report. Centre for Environmental Management of Degraded Ecosystems, School of Environmental Studies, University of Delhi, Delhi, 2006, p. 64.
11. Murali, K. S. and Setty, R. S., Effect of weeds *Lantana camara* and *Chromola odorata* growth on the species diversity, regeneration and stem density of tree and shrub layer in BRT sanctuary. *Curr. Sci.*, 2001, **80**, 675–678.
12. Champion, H. G. and Seth, S. K., *A Revised Survey of the Forest Types of India*, Government of India Publication, New Delhi, 1968.
13. Kumar, R. and Shahabuddin, G., Effects of biomass extraction on vegetation structure, diversity and composition of forests in Sariska Tiger Reserve, India. *Environ. Conserv.*, 2005, **32**, 1–12.
14. Curtis, J. T. and McIntosh, R. P., The interactions of certain analytic and synthetic phyto-sociological character. *Ecology*, 1950, **31**, 434–455.
15. Menhinick, E. F., A comparison of some species–individual diversity indices applied to samples of field insects. *Ecology*, 1964, **45**, 859–869.
16. Biodiversity Pro, 1997; <http://www.sams.ac.uk/dml/projects/benthic/bdpro>
17. *SPSS Base 7.5 Application Guide*, SPSS, Chicago, 1997, p. 389.
18. Fensham, R. J., Fairfax, R. J. and Cannell, R. J., The invasion of *Lantana camara* L. in Forty Mile Scrub National Park, North Queensland. *Aust. J. Ecol.*, 1994, **19**, 297–305.
19. Sharma, G. P. and Raghubanshi, A. S., Tree population structure, regeneration and expected future composition at different levels of *Lantana camara* L. invasion in the Vindhyan tropical dry deciduous forest of India. *Lyonia*, 2006, **11**, 25–37.
20. Gentle, C. B. and Duggin, J. A., *Lantana camara* L. invasions in dry rainforest–open forest ecotones: The role of disturbances associated with fire and cattle grazing. *Aust. J. Ecol.*, 1997, **22**, 298–306.
21. Macdonald, I. A. W., Kruger, F. J. and Ferrar, A. A., *The Ecology and Management of Biological Invasions in Southern Africa*, Oxford University Press, Cape Town, 1986.
22. Rai, J. P. N. and Tripathi, R. S., Allelopathy as a factor contributing to dominance of *Eupatorium riparium* Regel. *Indian J. Ecol.*, 1984, **9**, 14–20.
23. Lamb, D., Forest regeneration research for reserve management: Some questions deserving answers. In *Tropical Rainforest Research in Australia: Present Status and Future Directions for the Institute for Tropical Rainforest Studies* (eds Goudberg, N., Bonell, M. and Benzaken, D.), Institute for Tropical Rainforest Studies, Townsville, Australia, 1991, pp. 177–181.
24. Gentle, C. B. and Duggin, J. A., Allelopathy as a competitive strategy in persistent thickets of *Lantana camara* L. in three Australian forest communities. *Plant Ecol.*, 1997, **132**, 85–95.
25. Duggin, J. A. and Gentle, C. B., Experimental evidence on the importance of disturbance intensity for invasion of *Lantana camara* L. in dry rainforest–open forest ecotones in north-eastern NSW, Australia. *For. Ecol. Manage.*, 1998, **109**, 279–292.

ACKNOWLEDGEMENTS. Funding from Council of Scientific and Industrial Research, New Delhi is acknowledged. J.S.S. is supported by the INSA Scientist Scheme.

Received 2 January 2007; revised accepted 14 December 2007