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**Impact of *Lantana camara*, a major invasive plant, on wildlife
habitat in Bandipur Tiger Reserve, southern India**



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INTRODUCTION

A biological invasion is the successful establishment and spread of a species, usually exotic, in an ecosystem. Exotic plant species have been transported between countries and habitats as part of the modern global commercial interchange. Their invasion has been further facilitated through the large-scale disturbance of native habitats and plant communities. Thus, the cornerstone of the overall problem of biological invasions is the breakdown of natural biogeographical realms and their barriers.

In recent years, invasion by exotic species has come to be considered a leading cause of native species decline and habitat degradation. The invasion of natural communities, particularly conservation areas, by introduced plants constitutes one of the most serious threats to biodiversity and has been shown to profoundly alter ecosystem structure and function and aesthetic value of many habitats around the world. There are few ecosystems in the world that have not been invaded by terrestrial plants, especially flowering plants and conifers.

Most exotic plant invasions occur in forests, both natural and disturbed ones. Widespread destruction or conversion of primary tropical forest has paved the way for secondary succession that has often included heavy invasion by exotic plants. These invasions, particularly by woody species, constitute one of the most serious threats to native forest biodiversity. Yet intensive research on biological invasions over the last two decades has generally ignored tropical forests. The tropical dry forest is particularly severely invaded owing to its history of anthropogenic disturbance which is known to result in high numbers of exotic species. Dry forests in southern India are also critical habitats for globally threatened species such as the tiger (*Panthera tigris*), Asian elephant (*Elephas maximus*), gaur (*Bos gaurus*) and wild dog (*Cuon alpinus*). Yet exotic plant invasions in this endangered forest ecosystem, have hardly been addressed. In this project I focus on the tropical dry forest ecosystem in southern India, where I investigated the ecological impacts of an exotic plant invasion.

Lantana

The dry forests of southern India have been invaded by several exotic plants of which *Lantana camara* (Verbenaceae; *Lantana* henceforth) stands out because of its rapid spread, intensity of infestation, and tenacious resistance to cutting and burning. *Lantana* is a native of tropical America, and was introduced to India as an ornamental to be planted in gardens and hedges. Since then, the species has spread rapidly into both farm and forest lands, and is one of the most widespread, terrestrial invasive species in India today.

Considered by IUCN as one of the world's 100 most invasive species, and among the world's 10 worst weeds, *Lantana* is particularly abundant in India's dry-moist forests, growing in dense thickets and up to a height of 20m when it sends creeping branches into the canopy. *Lantana* grows on all types of well-drained soils and in a wide rainfall range (from seasonal dry forests to rainforest) but is also very drought-resistant. It rarely invades



Lantana camara was introduced in India as an ornamental. From gardens and greenhouses it spread into field and forest and today is one of India's most invasive species

undisturbed, closed-canopy forest but rapidly colonizes gaps, edges and disturbed or logged habitats. It produces large numbers of seeds that are dispersed by birds and the seeds germinate rapidly and easily. Under conditions of high light, soil moisture and soil nutrients *Lantana* is a very efficient competitor against native species. It can become the dominant understorey species in infested areas blocking natural succession processes, and reducing biodiversity.



Lantana produces a profusion of bird-dispersed seeds (L) which germinate rapidly, and can remain in the seed bank for several years. As a result, Lantana can invade and dominate the forest understorey (R).

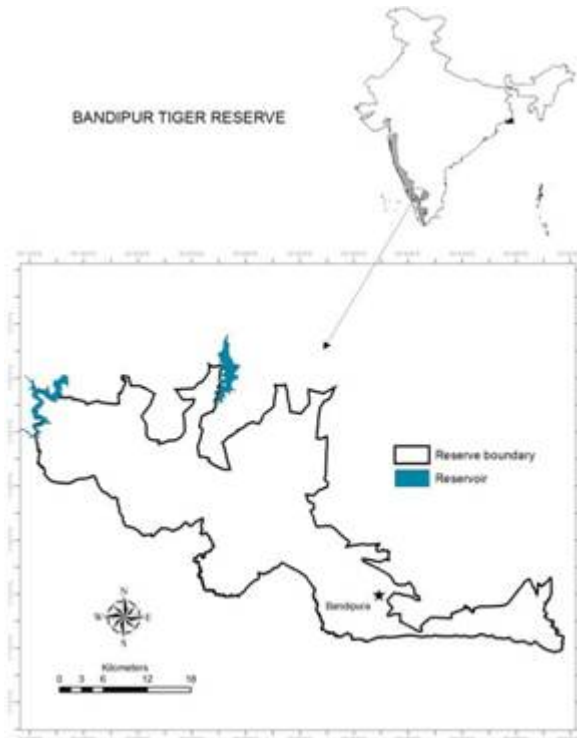
In much of the invaded dry forests of the Western Ghats, *Lantana* comprises up to three-fourths of the understorey biomass (A.E. Prasad, unpublished data). This astounding preponderance begs the question of what impacts this species is having on the native ecosystem in terms of structure, composition and process. Further, other forms of habitat degradation such as livestock grazing, and edge-creation may exert interactive effects along with *Lantana*. Its impacts may be numerous and varied, and can range from those on ecological processes, changes in native diversity and alterations to native disturbance regimes. Impacts on vegetation are also likely to affect herbivores, and the carnivores that depend on them. In other words, *Lantana* may be threatening the wildlife habitats in these forests, and thereby threatening important wildlife populations. I conducted this project in Bandipur Tiger Reserve, a tropical dry forest in the central Western Ghats in southern India, where *Lantana* is abundant, in some places, whereas native vegetation remains in others. This forest is also a critical habitat for populations of the tiger and its ungulate prey. This afforded me to study the impacts of this invasive plant, together with other co-occurring forms of habitat degradation on native flora and fauna.

STUDY AREA

Bandipur Tiger Reserve (BTR; 880 km²; 11°57' N, 76°12' E - 11°35' N, 76°51' E) in the foothills of the Western Ghats, is situated in the state of Karnataka. Bounded by protected dry deciduous forests in the west and south, Bandipur is part of an expanse of protected mixed deciduous forest over 5000 km² in area. The study area is monsoon-dependent and strongly seasonal with two main seasons – dry (January – May), and wet (June - December). Average annual rainfall ranges between 914 and 1270 mm with most of the rain falling during the wet season. Fires are common in the dry season which extends between January and May. In the dry season, trees shed their leaves, and flush soon after the pre-monsoon rains.

While *Anogeissus latifolia* Roxb. (Combretaceae), *Tectona grandis* Linn. (Verbenaceae) and *Terminalia* sp. (Combretaceae) are the dominant trees, *Phyllanthus emblica* Linn. (Euphorbiaceae), *Stereospermum personatum* Hassk. (Bignoniaceae) and *Schrebera swietenoides* Roxb. (Oleaceae) are also common. Some semi-evergreen and evergreen species, as well as bamboo (*Bambusa arundinacea*) are found in riparian and other moist areas. The native understory consists mainly of grasses (e.g. *Themeda cymbaria* Hack.) and shrubs (e.g. *Zizyphus* sp., *Canthium* sp., *Randia* sp., *Helicteres* sp.). BTR (together with other dry forests in the region) has been extensively invaded by exotic plants such as *Lantana camara* Linn., *Eupatorium odoratum* Linn., *Ageratum conyzoides* Linn. and *Parthenium hysterophorus* Linn.. Of these, *Lantana camara* (*Lantana*), is the most abundant (in areas of severe invasion, over three-fourths of the understory biomass is comprised of *Lantana*; A.E. Prasad unpublished data) and widespread exotic plant (72% of the BTR is *Lantana*-invaded, with 16 % under moderate-high levels of invasion; A.E. Prasad & M.D. Madhusudan, unpublished data).

BTR is a globally important conservation landscape for the tiger, and its ungulate prey which includes chital (*Axis axis*), sambar (*Cervus unicolor*), gaur (*Bos gaurus*), muntjac (*Muntiacus muntjak*) and wild pig (*Sus scrofa*). The study area has among the world's highest wild herbivore biomass densities (> 18,000 kg/km²). It is also home to two other large carnivores – the leopard (*Panthera pardus*) and the dhole (*Cuon alpinus*). It is part of the Nilgiri Biosphere Reserve which harbours among the highest densities of Asian elephant in the world. At least two species of primates also occur here – common langur (*Presbytis entellus*), and bonnet macaque (*Macaca radiata*). The 'natural' disturbance regime in this area consists mainly of dry season fires. However, care was taken to exclude from the study areas with recent burn history in order to distinguish the impacts of anthropogenic disturbance and invasive species from the possible varied effects of fire.



Bandipur Tiger Reserve is situated in the Western Ghats biodiversity hotspot in peninsular India

The study area is unique because there are no human settlements within it, as there are in most other protected areas of India. However, the forest experiences anthropogenic pressures of varying intensity through activities including Minor Forest Produce (MFP) collection, fuelwood harvest and livestock grazing.



Bandipur is an important habitat for gaur (L), and sambar (R), dominant prey species for tigers, as well as the Asian elephant

Study I

EXTENT AND SEVERITY OF *LANTANA* CAMARA INVASION
IN BANDIPUR TIGER RESERVE**Objectives**

Fundamental to any research addressing biological invasions is assessing the severity (abundance and spatial extent) of the invasion. In the case of *Lantana camara*, quantifying invasion has been difficult and very little is known about its spatial range and its abundance in invaded habitats. *Lantana* is extremely varied in its growth form ranging from individual widely-spaced clumps, to a dense tangle of stems, branches and twigs. It can range from less than a meter in height to vine-like branches that creep over six metres into the canopy. Because of its growth form which is both variable as well as often impenetrable, counting *Lantana* can be a formidable task. An alternative to counting is estimating biomass density by weighing *Lantana*. However, even this form of measurement would yield only point estimates of invasion severity and would be useful only at a local scale (of plots or sites). Weighing as a method of quantification would be too tedious to conduct at the landscape scale. Thus no plot-based or point estimates of *Lantana* could reliably or conveniently yield a bird's eye view of the extent and severity of invasion. Our objective was to identify a method of describing the abundance and distribution of *Lantana camara* at the scale of a forest.

USING SATELLITE IMAGERY — A satellite image of invaded areas in which *Lantana* was clearly discernible could assist in describing spatial patterns of invasion. One index of the 'amount' of vegetation present in a given location is Normalized Difference Vegetation Index (NDVI) which measures the 'greenness' on the ground. Thus *Lantana*, when green, could be represented by NDVI which could tell us where and how much *Lantana* is present. However *Lantana* occurs in the forest understory and its NDVI is obscured by the tree canopy. Understory vegetation, including *Lantana*, will become visible only when the canopy is absent. In deciduous forests, trees shed their leaves during the dry season. Therefore, a dry season NDVI image should reflect understory *Lantana* 'greenness' given two conditions: first, canopy trees have shed their leaves such that canopy NDVI is nil; second, *Lantana* has not shed its leaves such that it has 'greenness' which can be captured by a satellite sensor.

This image should be a close match of on-ground *Lantana* and may be used to map *Lantana* invasion on the ground. My objective was to test this by using dry season satellite imagery of Bandipur Tiger Reserve (taken at a time when, field observations confirmed that both the above criteria were true) in combination with other potential environmental predictors of *Lantana*, to predict the abundance of *Lantana* across BTR, and compare these predictions to ground estimates of *Lantana* abundance.

Methods

FIELD DATA COLLECTION — I sampled *Lantana* abundance at 108 locations distributed randomly across a 35 km² area in the central region of the Reserve. Abundance estimates were based on a visual assessment of thickness, along an 8-class scale ranging from 0 – absent to 7 – very dense. Then at 35 random locations in the same 35 km² area, I estimated *Lantana* thickness as well as cut and weighed *Lantana* within 2 m x 2 m plots in order to determine the relationship between *Lantana* thickness class and *Lantana* weight.



Lantana was cut and weighed in 2m × 2m plots to determine biomass density. This weight along with a subjective classification of *Lantana* thickness was used to ascertain severity and spread of invasion or abundance in the study area.

MAPPING *LANTANA* DISTRIBUTION — I extracted values of NDVI, and Bands 1 to 4 (spectral variables) for the 108 transect locations from an IRS 1C LISS III satellite image taken in February 2006 (dry season). I also extracted values of slope, and elevation (terrain variables) from a DEM of the area for these locations. I used ERDAS Imagine 9.1 (Leica Geosystems Geospatial Imaging) for the extractions. I then used these predictor variables to plot two separate regression

trees in R 2.6.1 - one model based on spectral and terrain variables and a second model based on only the spectral variables. Tree-based models use recursive partitioning, to split data and place them in classes based on classification rules. Ultimately, the initial dataset is progressively split to yield a tree with terminal bins for the final values of the response variable. The regression trees predicted mean *Lantana* thickness at a given location (response variable) at various levels of the predictor variables. Based on these regression trees I prepared an algorithm that would predict *Lantana* invasion across a landscape given values for the predictor variables. ERDAS Imagine 9.1 was used to prepare this spatial classification algorithm as well as the final *Lantana* classification maps for the entire Reserve (880 km²).

MAP VALIDATION — In order to validate the *Lantana* classification maps I sampled *Lantana* at 78 random locations across the Reserve using a similar 8-point classification scale. I also cut and weighed *Lantana* at each of these locations. I carried out a series of correlation analyses to assess how well *Lantana* abundance predicted by the classification maps matched ground estimates by comparing predicted values and estimated values for *Lantana* weight, and *Lantana* thickness class.

Results

Weight of *Lantana* was highly correlated with subjective 8-class scale of *Lantana* abundance (Kendall $\tau = 0.816$, $p < 0.001$; Figure 1).

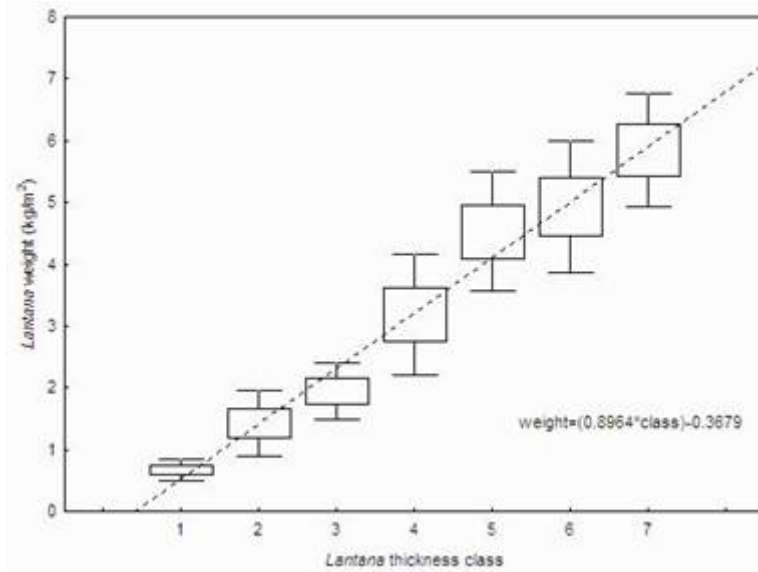


Figure1.

Subjective classification of *Lantana* thickness was closely matched ($\tau = 0.81$, $p < 0.001$) by weight of *Lantana* at the same locations. This regression model was used to convert estimated classes into *Lantana* weight. Boxes represent SE and whiskers represent SD about the mean.

The two regression trees (with both spectral and terrain variables, and with only the spectral variables) yielded two *Lantana* distribution maps for the Reserve (Figure 2a and b respectively).

When I compared the predicted *Lantana* abundance (both thickness class as well as weight) with ground-truth estimates I found that for both classification maps estimated and predicted *Lantana* thickness class were significantly correlated (with $p \ll 0.001$; See Table 1 for Kendall correlation coefficients τ). However, the map based on the regression tree with only spectral predictor variables predicted *Lantana* abundance (both thickness and weight) better than the map based on both terrain and spectral variables.

Variable compared	Map1 – terrain+spectral data			Map2 – only spectral data		
	τ or r	r^2	Z	τ or r	r^2	Z
Thickness class	0.4947	-	6.4101	0.5027	-	6.5127
Weight	0.5135	0.2636	-	0.6037	0.3645	-

Table 1.

Results of correlations comparing predicted and estimated values of *Lantana* abundance. Thickness classes were compared using a Kendall's (τ or tau) non-parametric correlation whereas weights were compared using regular parametric correlation. Both correlations were statistically significant ($p < 0.001$).

LANTANA IN BANDIPUR TIGER RESERVE — The first map, based on all variables, predicts moderate-dense *Lantana* in about 15% of the Reserve (approx. 130 km²), with most of the area under sparse or no *Lantana*. However, the map based on only the spectral variables shows that *Lantana* is absent from 45 km² (5 % of the Reserve area), and is sparse in 380 km² (43.5 % of the Reserve area). Moderate levels of *Lantana* cover 440 km² (50 % of the Reserve area), and the remaining area of 13 km² (1.5% of the Reserve area) is covered by dense to very dense levels of *Lantana* (over 5 kg/m²).

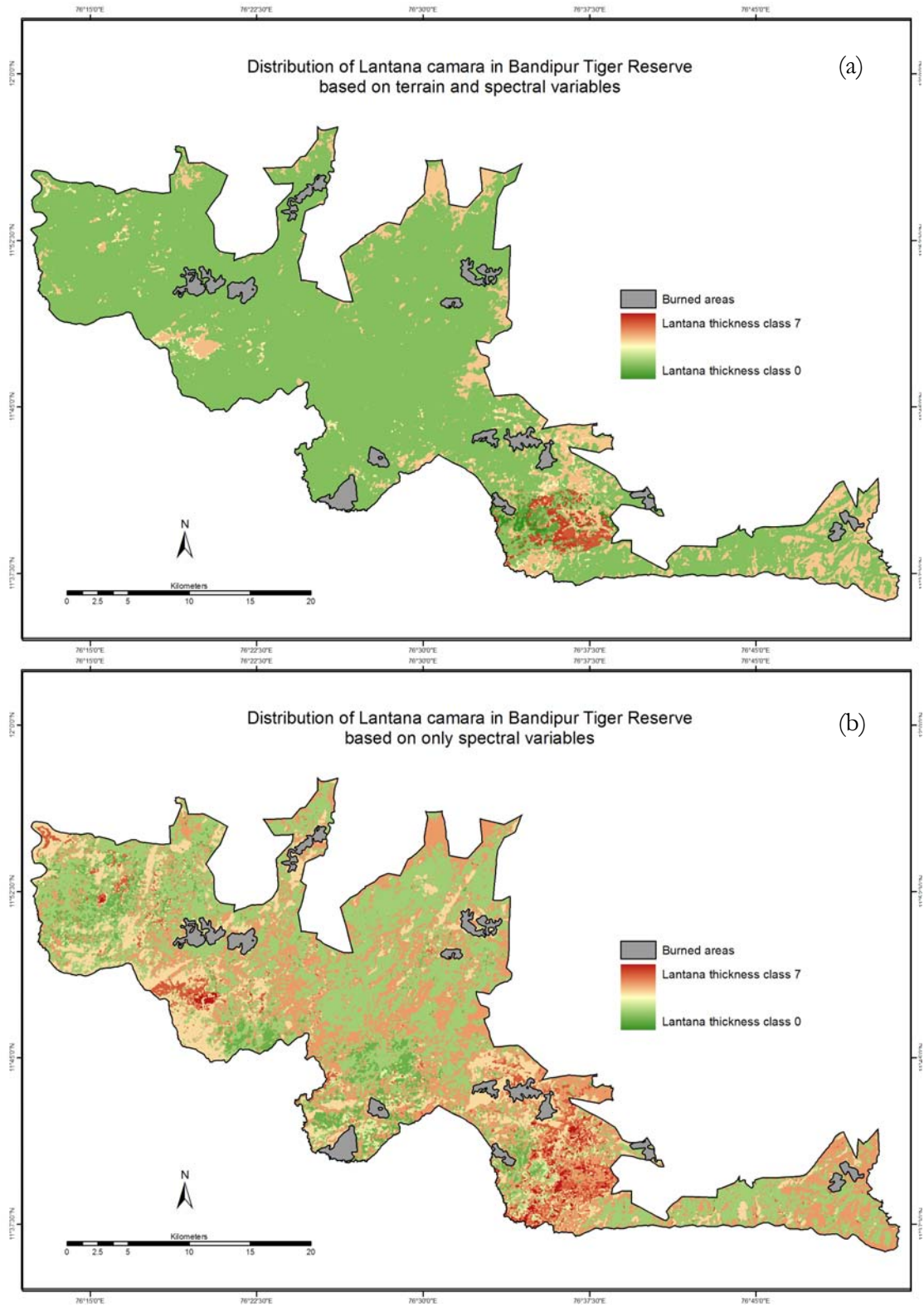


Figure 2.

Distribution of *Lantana* in Bandipur Tiger Reserve mapped based on (a) both spectral and terrain variables (b) only spectral variables.

Conservation Implications

The approach tested and presented here may be used to map *Lantana* in deciduous forests where understory greenness may be captured in the 'right' season. In India, deciduous forests (moist and dry) cover over 500,000 square kilometres and comprise over 40% of all forested land area. This means, that the approach I present here is applicable in a vast area, albeit with appropriate modifications to the model based on different forest characteristics and field conditions. Since *Lantana* has been reported from forests across the country, the use of satellite data (and other relevant predictors) to describe the spatial extent and severity of invasion at the scale of forest patches could prove valuable in greater research into the ecology and management of this invasive plant.

Further, both maps presented here show that *Lantana* has invaded a large portion of the Reserve. Although very dense *Lantana* appears to occur in only 1% of the Reserve, between 13 and 50% (Map1 and Map2 respectively) of the Reserve is under moderate levels of invasion. This should not be surprising as *Lantana* is known to spread rapidly, thrive in disturbed habitats and recover quickly from mechanical damage. However, this furthers emphasizes the urgency of the need to pay greater research and scientifically-sound management attention to this species. Studies from invaded sites around the world and in India, including other concurrent research by the author have shown that *Lantana* can suppress native forest regeneration, reduce native plant species richness, increase fire, and out-compete native vegetation via shading and allelopathy. Therefore, I draw attention to a real and ubiquitous, yet underestimated and little understood threat to forest biodiversity.

Study II.

INFLUENCE OF *LANTANA CAMARA* IN EDGES ON TREE COMMUNITY DYNAMICS**Objectives**

In already disturbed or fragmented forests, exotic plant invasion promoted by edges is being increasingly documented. Clearings such as roads and streams apparently enhance exotic species invasion by acting as corridors or agents for dispersal, providing suitable habitat, and containing reservoirs of propagules for future episodes of invasion. Thus, it is now widely known that the flux of exotic plants into forest interiors is promoted by edges, and is a widespread and important 'edge effect', the ecological impacts of which have gone largely unaddressed.

The invasion of *Lantana camara* in Bandipur Tiger Reserve also spatially co-occurs with roads and their view-lines, and other clearings (such as fire-breaks, waterholes and salt-licks). Further, the greatest abundance of *Lantana* is found in and along these edges (*Lantana* density in places exceeds 8 kg/m² and comprises over 75% of the forest understory). While most roads and clearings are bordered by dense *Lantana*, others have native understorey.



Dense *Lantana* thickets border most roads and view-lines, dominating the forest understory. Here, the *Lantana* on the right has lost its leaves in a dry season fire, while unburned thickets have remained green.

Thus, these edges not only exert independent edge-effects on native biodiversity, particularly vegetation, but edge-promoted *Lantana* invasion also likely has concomitant effects. Here I discuss the role of edge-related *Lantana* invasion in influencing native vegetation patterns, particularly tree community structure and composition. My objectives were to determine the impacts of edges, and *Lantana* in edges on patterns of tree death and composition in Bandipur by comparing tree death (density of dead trees) and extant tree community composition between forest edges and interiors, as well as between exotic (dominated by *Lantana*) and native forest understory.

Methods

STUDY AREA —The study area (32 km²), located in the south-eastern part of the Reserve, has 72 km of roads. These roads together with view-lines along roads, which are maintained for wildlife tourism by cutting and burning, comprise edge which varies in width between 30-40 m (wide) along most roads, and 10-12 m (narrow) along others. Further, while most roads and clearings are bordered by dense *Lantana*, others have native understory comprising mostly of tall grass (e.g. *Themeda cymbaria*) and shrubs (e.g. *Zizyphus* sp., *Canthium* sp. *Randia* sp., *Helicteres* sp.). Thus, management practices in the study area, that maintain artificial edges and clearings, along with variation in understory offer a natural experiment to document tree death, and tree community composition with respect to edge-associated *Lantana* invasion. Comparison of tree death, and composition in edge and interior was nested within comparisons across factorial combinations of understory-type (two levels – native and exotic) and edge-width (two levels – wide and narrow).

DATA COLLECTION — Within this factorial experimental design, I counted trees in paired plots (at the edge and in the interior i.e., 50 m away from the edge) at n = 10 random locations in each of the factorial combinations of edge-width and understory-type (native-narrow, native-wide, exotic-narrow, exotic-wide). In each plot (10 m radius; n = 80 plots overall) I noted (i) the total number and species of trees (> 15 cm girth at breast height) (ii) number of dead trees (including snags, stumps and fallen trees). I collected these data between October 2006 and January 2007.

STATISTICAL ANALYSES: TREE DEATH— I used a Generalized Linear Model (Poisson distribution; log-link) to test for the effects of edge, edge-width and understory on number of dead trees per plot. The GLM would show the relative roles of edge, understory and edge-width in explaining variation in tree death. Additive effects of edge (location), understory-type, edge-width, and the edge-width × understory-type interaction were analyzed sequentially with statistical significance adjudged at $\alpha = 0.05$. All analyses using Generalized Linear Models were conducted in R Version 2.6.1. Bray-Curtis dissimilarity indices were calculated using PRIMER 5 Version 2.2.2 (Primer-E Ltd., 2001).

STATISTICAL ANALYSES: TREE COMMUNITY COMPOSITION — After calculating Bray-Curtis dissimilarity indices for differences in composition of live trees between all pairs of plots, I used an Analysis of Similarities (ANOSIM) in PRIMER 5 Version 2.2.2 (Primer-E Ltd., 2001) to determine whether compositional dissimilarity of the live tree community was significantly different at all levels of edge (location), edge-width and understory. I also used the Similarity Percentage (SIMPER) function in PRIMER 5 Version 2.2.2 (Primer-E Ltd., 2001) to examine the contribution of each species in a plot to the average Bray-Curtis dissimilarity between groups of samples (Primer-E Ltd., 2001), to determine what species contributed to

the compositional dissimilarity between groups or factors and how much each species contributed.

Results

A total of 573 trees from 51 species were encountered during sampling. Total number of trees per plot ranged from three to 17, and the number of live trees per plot varied from one to 16. Seventy percent of plots (56 out of 80) had at least one dead tree.

TREE DEATH — Variation in density of dead trees was best explained by location with respect to edge ($\chi^2 = 20.77$, $p < 0.001$) with edge plots (1.8 ± 0.1 SE) having over twice as many dead trees as interior plots (0.7 ± 0.1 SE). However, a significant proportion of the remaining variation in dead tree density was explained by the interaction between width and understory ($\chi^2 = 4.96$, $p = 0.02$). Plots associated with wide edges bordered by *Lantana* understory had more dead trees (1.55 ± 0.3 SE) than plots in either narrow edges with *Lantana* understory (1.09 ± 0.2 SE) or wide edges with native understory (0.9 ± 0.2 SE; Figure 1.). Although the difference was not statistically significant, on average (between edge and interior), plots with *Lantana* had greater density of dead trees (1.31 ± 0.18 SE) than plots with native understory (1.21 ± 0.21 SE).

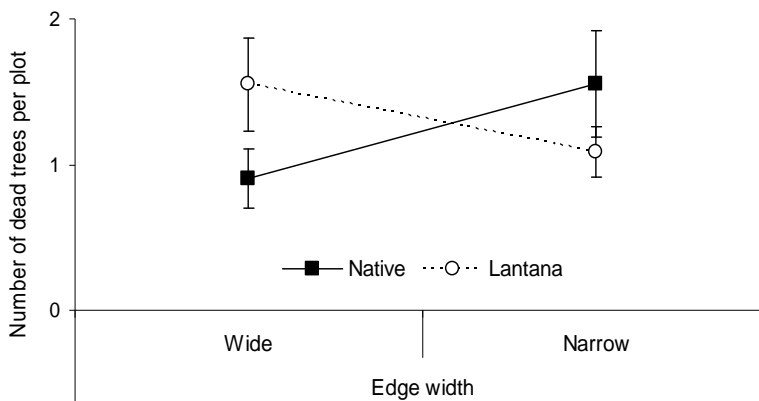


FIGURE 1.

Effect of edge-width (wide vs. narrow) and understory-type (native vs. invasive) on mean number of dead trees in a dry tropical forest of Western Ghats, southern India. Data are from 10 m radius plots ($n = 80$) in Bandipur National Park. Error bars represent ± 1 SE.

TREE COMMUNITY COMPOSITION — The ANOSIM (comparing pair-wise differences in community composition of plots across edge (location), edge-width, and understory type) showed that plots with *Lantana* had a significantly different composition of live trees from plots with native understory (Global $R = 0.152$, $p = 0.001$). However, plot location (edge vs. interior) did not influence extant tree community composition (Global $R = 0.009$, $p = 0.22$).

The SIMPER analysis showed that plots associated with a native understory had within-group dissimilarity of 37.6 percent, while those with *Lantana* understory had average within-group dissimilarity of 40.1 percent. However, average dissimilarity between native and *Lantana* understory groups was 62.7 percent. While *Anogeissus* and *Terminalia* were more abundant in native understory, *Tectona* and *Phyllanthus* were more abundant in plots with *Lantana*.

Conservation Implications



A dead tree standing in a *Lantana* thicket. This dataset suggests that *Lantana* invasion increases tree death along edges.

TREE DEATH — The density of dead trees at edges (1.8 dead trees/plot ± 0.1 SE) being 160 percent greater than that away from edges (0.7 dead trees/plot ± 0.1 SE), greater edge-related tree death is not only statistically but also ecologically significant. In other words, edge creation appears to be strongly contributing to increased tree death in these already-disturbed ecosystems. Further, this dataset suggests that edge-related exotic plant invasion may be driving significant and important tree community changes in invaded dry tropical forests. Although tree death was only slightly higher in areas with *Lantana* understory (1.3 ± 0.18 SE) when compared to native understory (1.21 ± 0.21 SE), the effect of *Lantana* is significant when clearings are wide. That is, wide clearings bordered by *Lantana* have significantly greater density of dead trees implying that fragmented and disturbed forests that are subsequently invaded by exotic plants are in danger of losing their tree communities. Since little is yet known about the ecology of *Lantana* in these

forests, the mechanism by which *Lantana* increases tree death, particularly in wide edges cannot yet be discussed. However, *Lantana*-promoted forest fires appear to be a likely mechanism. *Lantana* is known to increase the frequency of fires, and *Lantana*-promoted fires can have direct as well as indirect impacts on trees. Severe fires burn trees and directly cause their death. Indirectly however, fires reduce soil moisture as well as expedite the abscission of leaves from trees before trees have time to retract nutrients such as phosphorus from their leaves. Consequently, nutrient and moisture-deprivation likely exacerbate tree death in invaded forests where fire is common. Regardless of the mechanism, it is clear that *Lantana* invasion, particularly in edges, is leading to a loss of tree cover in these already endangered dry forest ecosystems, and critical wildlife habitats.

TREE COMMUNITY COMPOSITION— This study not only shows that *Lantana* in edges is increasing tree death, but also invaded forests have different tree species composition from forest with native understory (Global $R=0.135$, $p=0.001$). *Phyllanthus* and *Tectona* were more abundant in invaded forest while *Anogeissus* and *Terminalia* spp. were more abundant in *Lantana*-free forest. Despite the lack of an explanatory mechanism, it is important to note that exotic plants in edges are impacting native tree communities.



Plate 3.

Lantana-invaded forests are more prone to devastating fires that sometimes reach the canopy, and can kill trees. Charred stems of *Lantana* are visible in the understory.

Further, concurrent research by the author elsewhere in the study area has shown that *Lantana* has significant impacts on understory species abundance and composition including tree seedlings (A.E. Prasad, unpublished data). Thus, *Lantana* appears to be altering vegetation community structure and composition in these endangered forests, particularly in and along edges.

Greater tree death and changes in native tree community composition in invaded forests could eventually transform this woodland ecosystem into degraded open habitat, heavily invaded by exotic plants. Vast expanses of important habitat for wildlife including globally threatened species like the tiger, gaur, and Asian elephant would also be rendered unsuitable for wildlife. Thus, the ecological repercussions of this invasion for forests and their wildlife must no longer go unaddressed. The creation and maintenance of forest edges, in general and even for management purposes, must be minimized. When necessary, clearings and edges must be kept as small as possible. Further, the urgency of the need to better understand impacts of exotic plant invasions, particularly in edges, and methods to combat them, in this endangered forest ecosystem cannot be overstated. The factors investigated here are only few of a range of possible local drivers of ecological change in this endangered dry forest ecosystem, which includes livestock-grazing, fuelwood harvest, fire, changes in rainfall patterns and debarking by elephants. Further research into these factors and their roles in influencing patterns of tree death and altering tree communities is vital for understanding the dynamics of dry forests. Trees largely determine forest architecture and microclimate, and hence changes in tree-community dynamics may strongly affect other forest species and ecological processes. The future of these forests and their biodiversity hinges on greater research and management attention focussed on edges, associated exotic plant invasion and other drivers of degradation.

Study III.

IMPACTS OF *LANTANA CAMARA* AND LIVESTOCK ON FOREST VEGETATION, AND HERBIVORES.**Objectives**

Lantana is now ranked among the world's 100 most invasive species. Studies on the ecology and impacts of *Lantana* have found that in disturbed native forests it can become the dominant understorey species, disrupting succession and decreasing biodiversity. Its allelopathic qualities can reduce vigour of plant species nearby. At some sites, *Lantana* infestations have been so persistent that they have completely stalled the regeneration of rainforest for three decades. In India, surveys from the Himalayan foothills have reported that *Lantana* reduces species richness and suppresses regeneration in native tree populations. Yet, experimental evidence for the role of *Lantana* in altering the structure and composition of native vegetation, particularly understory species, is lacking. I addressed this lacuna in our current knowledge through an experiment comparing the structure and composition of native forest vegetation in plots where *Lantana* was present and those where it was experimentally removed.



Livestock (goats and cattle) from villages adjoining the Reserve graze within the forest. Here, livestock may be seen grazing amidst *Lantana*.

In addition to *Lantana* invasion, the dry forests of the Western Ghats experience a variety of forest resource-exploitation forms including livestock grazing, fuelwood harvest, minor forest produce collection, and tourism. Here I focus on livestock grazing. Although wildlife reserves constitute less than 5% of India's total area, 3/4th of them are grazed by livestock. Thus livestock-grazing is both a real and widespread presence in wildlife habitats across the country. Livestock can be strong drivers of structural and compositional change in plant communities.

While studies from India

elsewhere have documented the adverse effects of livestock grazing on forest vegetation, data on the combined effects of exotic plants and livestock on native vegetation communities are yet lacking. In this study I investigated the impacts of livestock grazing together with *Lantana* on native forest vegetation.

I studied the long-term effect of livestock grazing on forest vegetation by comparing vegetation structure and composition between livestock-grazed (LG) and livestock-free (LF) forest. Within each of these livestock strata I explored the short-term impacts of *Lantana* by comparing vegetation structure and composition between areas where I experimentally

removed *Lantana* (Cleared) and areas where I left *Lantana* as it was (Control). Changes in forest vegetation structure and composition suggest changes to the type and abundance of forage for wild herbivores which are likely to respond via differential habitat use. Therefore, I compared levels of wild herbivore habitat use across each of these experimental strata (LG-Control, LF-Control, LG-Cleared, and LF-Cleared).

The specific objectives of the study were to determine the independent and combined impacts of *Lantana* and livestock on

1. tree density, richness and composition.
2. tree seedling density, recruitment, survival, richness, and composition
3. native understory herb and shrubs density, richness and composition
4. grass volume
5. wild herbivore plot use

Methods

DATA COLLECTION — I selected two ecologically and topographically similar areas, one of which experienced livestock grazing (livestock-grazed) and one which was free of livestock (livestock-free). In each of these areas I laid 30 plots measuring 15 m × 15 m each. In 20 out of these 30 plots I cleared *Lantana* by cutting and uprooting (Cleared). In the remaining 10 plots I left *Lantana* as it was (Control). In these 15 m × 15 m plots I quantified adult trees and herbivore plot use. Further, within each of these large plots I laid four smaller sub-plots (3 m × 3 m) within which I measured tree seedlings, native herbs and shrubs, and grass. Using this experimental design I quantified the following variables:



A tagged *Anogeissus latifolia* seedling

(i) Trees: Number, and species of each adult tree in the large plots

(ii) Tree seedlings: I counted every seedling of 11 native tree species. I also tagged these seedlings and monitored their recruitment and survival of.

(iii) Native herbs and shrubs: I counted every individual of 11 native herb-shrub species.

(iv) Grass: Within each of the four sub-plots calculated standing volume of grass, by multiplying area covered by grass with average grass height.

(v) Herbivores: I estimated herbivore plot-use by counting dung/pellet groups of 4 wild

herbivores (chital *Axis axis*, sambar *Cervus unicolor*, gaur *Bos gaurus*, elephant *Elephas maximus*) as well as livestock - cattle, sheep and goats). In each large plot I recorded number of dung/pellet groups within a 3 m × 15 m belt located along one side of the plot. I quantified each of these variables once in each season (premonsoon1: May-June 2006 (Time0), post-monsoon: September-October 2006 (Time1), early dry: January-February 2007 (Time2), pre-monsoon2: May-June 2007 (Time3), with a total of four repeated measures during a one-year period.

STATISTICAL ANALYSES

Species Richness: I estimated species richness of different strata of forest vegetation using species rarefaction curves. I used Microsoft® Excel (Microsoft Corporation 2002) for data compilation and plotting species rarefaction curves.

Community Composition: First, I created Bray-Curtis dissimilarity matrices for each stratum of forest vegetation - trees, tree seedlings, and herbs and shrubs. Then I used Multi-Dimensional Scaling (MDS), one-way Analysis of Similarity (ANOSIM) and analyses of percent similarity (SIMPER) to compare species composition of these variables across plots differing in the experimental factors (livestock and *Lantana*) in each season. I used PRIMER 5 (Primer-E Ltd. 2001) for these analyses.

Vegetation Structure: I determined the effects of *Lantana* and livestock on forest vegetation and herbivores using repeated measures Analyses of Variance (ANOVA), with time as a within-group factor, and *Lantana* and livestock as predictors. Statistical significance of ANOVA results were adjudged at $\alpha=0.05$. I used Microsoft® Excel (Microsoft Corporation 2002) for data compilation, basic descriptive data analyses, and plotting frequency distributions, and STATISTICA 6.1 (data analysis software system; StatSoft Inc. 2003).

Herbivores: I compared plot-use by herbivores across seasons, and across the factorial combinations using repeated measures ANOVA with time as a within-group factor and *Lantana* and livestock as between-group factors ($n=59$, $\alpha=0.05$). Microsoft® Excel (Microsoft Corporation 2002) and STATISTICA 6.1 (StatSoft Inc. 2003) were used for these analyses.

Results

Here I present only key results from the several analyses performed for five response variables – trees, tree seedlings, herbs and shrubs, grass, and herbivores.

Species Richness:

Neither *Lantana* nor livestock had significant impacts on the species richness of trees and tree seedlings.

HERBS AND SHRUBS — Clearing had an immediate effect on species richness of herbs and shrubs in the livestock-free area, with an increase of 3 species after clearing. In the livestock-grazed area, however, this effect was absent with neither time nor clearing having any effect on average species richness. It appears that the presence of livestock compensates for the absence of *Lantana*, keeping the species richness the same.

Community Composition:

TREES — The Analysis of Similarity (ANOSIM) showed that tree species composition in livestock-grazed and livestock-free plots differed significantly (Global $R=0.199$, $p=0.001$).

TREE SEEDLINGS — Tree seedling species composition varied across the four main experimental strata (livestock+*Lantana*, only livestock, only *Lantana*, and neither) as indicated in the MDS ordination (Figure 1). This was confirmed by the ANOSIM results (Global $R=0.91$, $p=0.001$). ANOSIM analysis confirmed that species composition varied significantly in relation to livestock grazing both in the presence as well as absence of *Lantana* (Global $R=0.958$, $p=0.029$, and Global $R=0.604$, $p=0.029$ respectively), as well as in relation to *Lantana* presence under both levels of livestock (livestock-grazed, Global $R=0.76$, $p=0.029$; livestock-free, Global $R=1.0$, $p=0.029$).

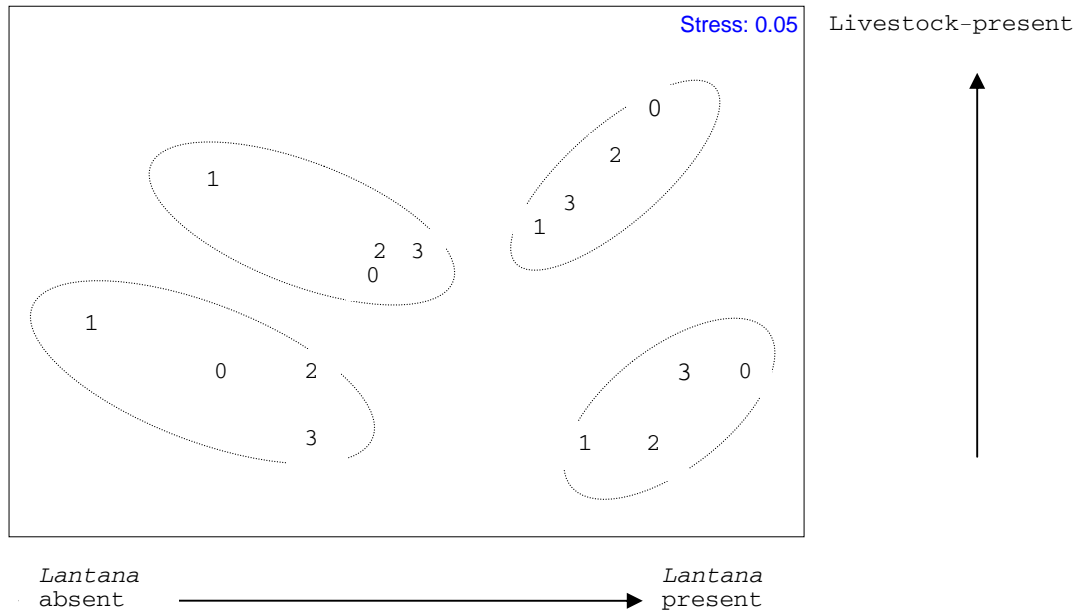


Figure 1.

MDS plot of tree seedling species composition comparing plots with both livestock-grazing and *Lantana* (filled triangles ▲), only livestock-grazing (empty triangles Δ), only *Lantana* (filled squares ■), and neither livestock nor *Lantana* (empty squares □). The numbers represent time step, with 0 referring to the start of the experiment, and 3 the end.

HERBS AND SHRUBS— The presence of livestock and the removal of *Lantana* changed herb and shrub species composition as well (Global $R=0.452$, $p=0.001$). Livestock increased the abundance of unpalatable, weedy species such as *Stachytarpheta jamaicensis* and *Barleria buxifolia*.

Vegetation Structure

TREE SEEDLINGS — Densities: Season had a significant impact on seedling densities ($F_{3,165}=40.2$, $p<0.001$) with highest densities in the post-monsoon season (Sep-Oct 2006). Similarly, the interaction effect of *Lantana* with season was also significant ($F_{3,165}=4.4$, $p=0.005$) possibly due to greater influence of seasonal variation in plots without *Lantana*. Survival: Livestock had no effect on the survival of tree seedlings (proportion of seedlings which survived per plot). *Lantana*, however, had a significant effect on seedling survival ($F_{1,55}=21.42$, $p<0.001$) with plots where *Lantana* was present having higher proportion of seedlings survive than plots where *Lantana* was removed. Time also had a significant effect on seedling survival ($F_{2,110}=9.475$, $p<0.001$). Recruitment: Seedling recruitment was not affected by either of the experimental factors, i.e., livestock or *Lantana*. Time however had an extremely significant effect on the proportion of seedlings recruited per plot ($F_{1,55}=119.98$, $p<0.001$), with recruitment being over 90 times higher immediately after the rains than in any other season.

HERBS AND SHRUBS — Both livestock-grazing, *Lantana* and season had significant effects on the density of native herb and shrubs ($F_{1,55}=13.83$, $p=0.000$; $F_{1,55}=16.78$, $p=0.000$; $F_{3,$

$F_{1,65}=35.93$, $p=0.000$ respectively). Further, the interaction effects of all factors were also significant. As seen from Figure 2, in the presence of *Lantana* HS densities were higher when livestock are present; conversely, when *Lantana* was removed HS densities were reduced to similar levels in both livestock-grazed and livestock-free areas.

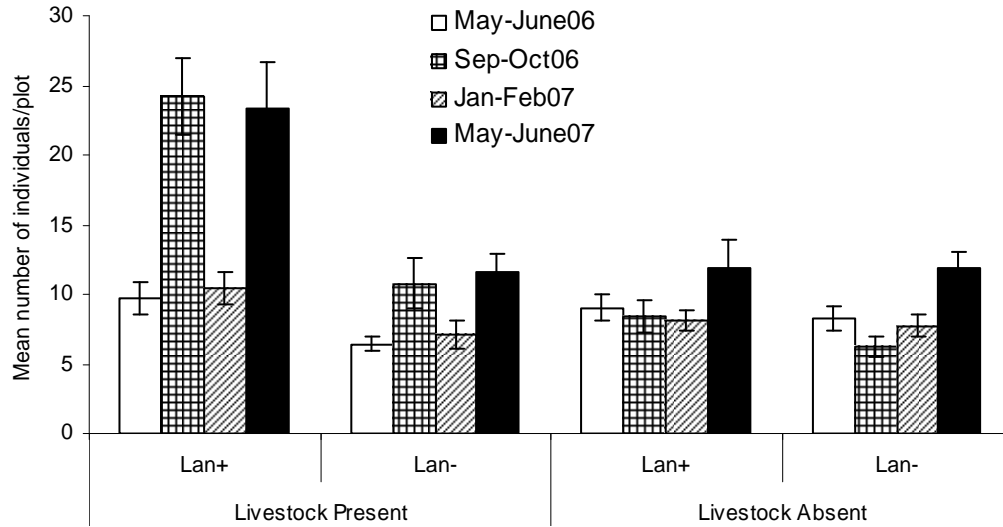


Figure 2.

Mean density of herbs and shrubs across livestock and *Lantana* treatments, over 4 seasons. Error bars represent 1 SE.

GRASS VOLUME — In areas both with and without livestock, *Lantana* presence appeared to increase grass volume (Figure 10). The difference in grass volume between control plots (with *Lantana*) and cleared plots (without *Lantana*) in both livestock treatments was highly significant ($F_{1,55}=49.62$, $p<0.001$). Further, in plots where *Lantana* was present, the livestock-free plots had higher grass volume than the livestock-grazed plots ($F_{1,55}=4.42$, $p=0.04$). Similarly, time also had a significant effect on grass volume ($F_{3,165}=5.71$, $p=0.001$) with a distinct post-monsoon peak (Sep-Oct 2006) in all plots except plots with *Lantana* in livestock-free areas.

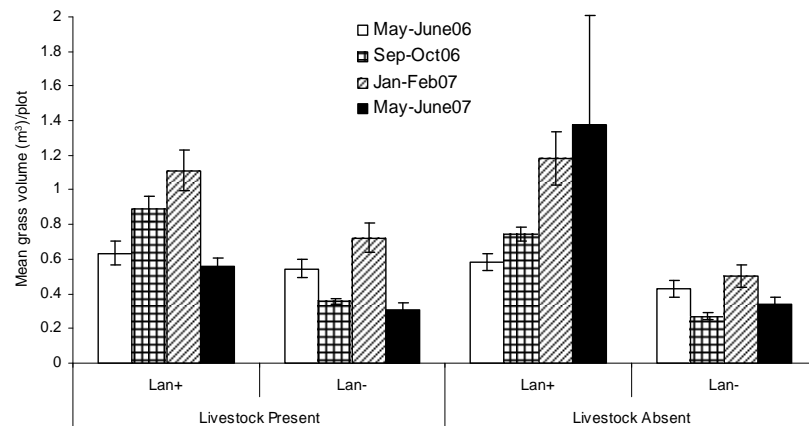


Figure 3. Mean grass volume (m³) across experimental treatments and four seasons.

Herbivores

CHITAL — The ANOVA showed that time significantly affected chital plot-use ($F_{3,165}=6.73$, $p=0.00$), with peaks in the post-monsoon season in all plots, as well as a second peak in the last season in all but the plots with *Lantana* in the livestock-free area. No other factors, either independently or interactively affected chital pellet-group density.

SAMBAR — Time appeared to have a strong influence on sambar ($F_{3,165}=11.1$, $p<0.001$) with an early dry season peak (Jan-Feb 2007) in sambar pellet-group density in all four types of plots. *Lantana* appeared to decrease sambar plot-use in livestock-free area whereas it increased it in the livestock-grazed area. This resulted in an overall significant effect of *Lantana* on sambar plot-use ($F_{1,165}=8.32$, $p=0.005$).

GAUR — As in the other herbivore species, gaur plot-use also appeared to be significantly affected by time or season ($F_{3,165}=6.24$, $p=0.000$), and showed a sharp peak in Sep-Oct 2006 season (Figure 4). Livestock also had significant main effects on gaur ($F_{1,55}=14.48$, $p=0.000$) with markedly lower gaur dung-groups encountered in plots where livestock were present (Figure 4).

ELEPHANT — Neither livestock nor *Lantana* had any main or mixed effects on elephants. However, season appeared to influence elephant use of these plots as time had a significant effect on dung-density ($F_{3,165}=5.55$, $p=0.001$).

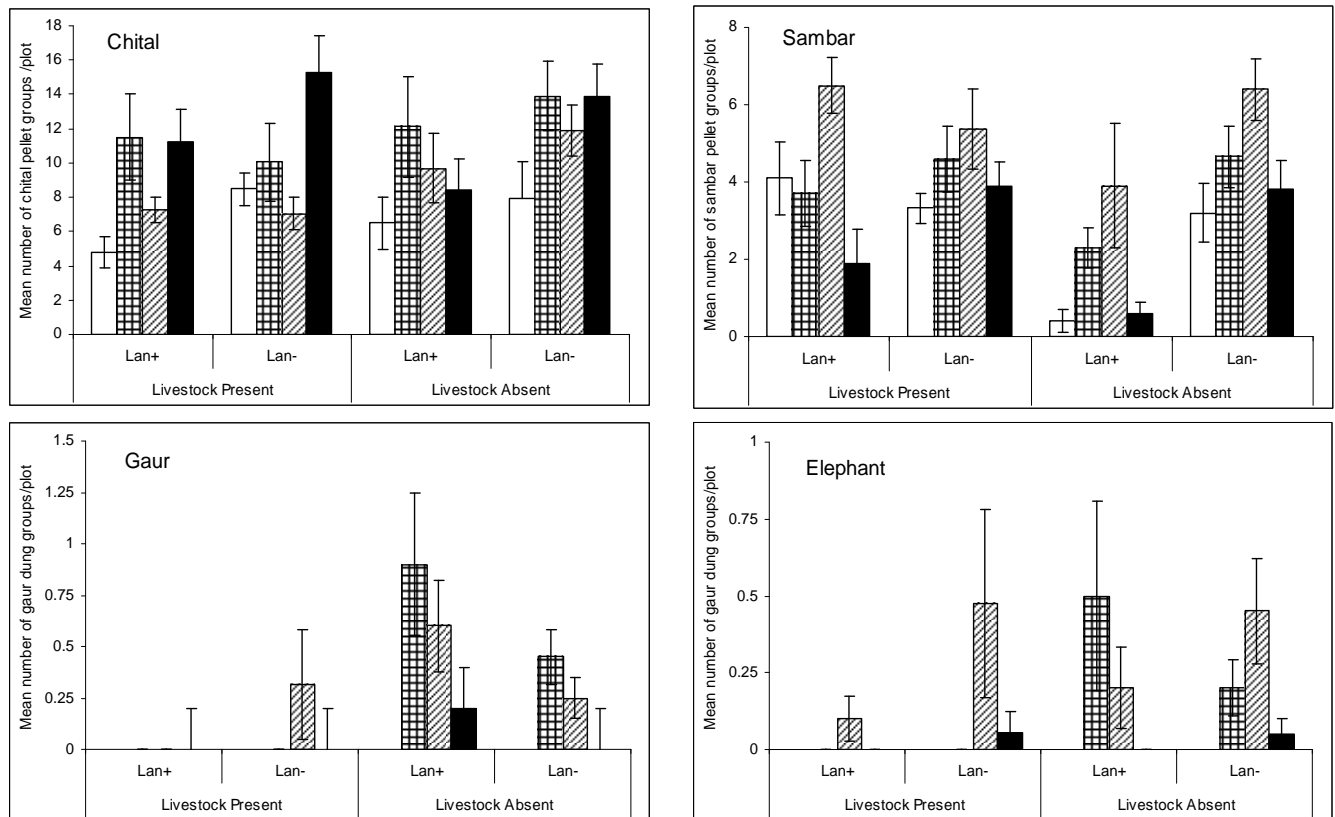


Figure 5.

Wild herbivore plot use in response to livestock and *Lantana* across four seasons (white – May-June 2006, dotted – Sep-Oct 2006, checked – Jan-Feb 2007, black – May-June 2007)

Conservation Implications

It is clear that in this habitat type vegetation as well as wild herbivore movement and habitat use are strongly seasonal. However intra-annual variation *within* varying levels of livestock and *Lantana* are for several variables significantly less than that *between* them. Livestock grazing is driving significant changes in vegetation community composition particularly of tree seedlings and herbs and shrubs, leading to the dominance of less palatable, grazing-resistant weedy species. Even if overall abundance of seedlings and grass is similar in areas with and without livestock, their composition is very different. In other words, even if both LG and LF areas appear 'green' their composition and possibly resultant forage availability vary significantly. Intra-annual forage resource fluctuation (of native herbs and shrubs as well as grass) is higher when livestock are present, rendering livestock-grazed areas less favorable for wild herbivores. Livestock also reduce habitat use by wild herbivores particularly gaur but also chital. Livestock pressures in these forests are chronic and appear to have driven changes in forest structure and composition.

Lantana on the other hand, is a much more recent phenomenon, which in its short history has already contributed to significant changes in the abundance and diversity of forest vegetation such as native herbs and shrubs, tree seedlings and grass. *Lantana* is clearly reducing species richness of native understory species while also causing compositional changes in the herbs and shrubs, as well as tree seedlings. Thus *Lantana* invasion may be driving these forests to an alternative type dominated by different species than in pre-invasion forests. *Lantana* also seems to increase the abundance of grass and herbs and shrubs, and the survival of tree seedlings by reducing herbivory. While this, when viewed in the short term, may appear a positive influence on vegetation, the reduced access of this forage to wild herbivores may be rendering vast tracts of *Lantana*-invaded forest poor ungulate habitat. Both from an ecological as well as conservation point of view, loss of ungulate habitat could be disastrous as keystone species such as tigers and other large carnivores which depend on this ungulate prey-base will also slowly disappear from these invaded forests.

Both livestock as well as *Lantana* are exotic to these forests, having evolved in isolation from native vegetation and wildlife. Together, these two alien influences could be gradually changing these tropical dry forests, causing significant structural and compositional changes in the vegetation which is likely to have cascading effects on consumer communities, in addition to altering the dynamics and function of this endangered ecosystem. While this study has highlighted some impacts on native forest vegetation and large mammals, impacts on other taxa such as birds, and invertebrates have not even been addressed yet. The conservation of this endangered forest and its wildlife perhaps hinges on addressing the role of these two pervasive factors in driving ecological change.

CONCLUSION

The keys findings of this project may be summarized as:

1. The spread and severity of *Lantana camara* invasion in a tropical dry deciduous forest may be described spatially using dry season satellite imagery, other predictor variables and limited field surveys.
2. *Lantana camara* in edges, particularly large clearings increases tree death and significantly alters extant tree community composition.
3. *Lantana* together with livestock grazing alters species composition of understory species, and tree seedlings. It also shields grass, understory vegetation and tree seedlings from herbivory, thereby increasing their density beneath thickets. However, this renders large amounts of forage inaccessible to wild herbivores, which are prey for large carnivores like the tiger. Thus it may have food-web level impacts and decrease the suitability of this habitat for wildlife. Livestock presence significantly reduces habitat use by grazers such as the gaur and chital, but appears not to affect sambar, which is primarily a browsers.

In summary, *Lantana*, together with edge-creation and livestock-grazing, and possibly other concurrent forms of habitat degradation is driving significant changes in the structure and composition of these habitats. As a result, consumers, which depend on forest vegetation, are also likely to be affected. And in turn, their predators would also be expected to decline as their prey populations decline. Thus, *Lantana* appears have to potential to exert ecosystem and food-webs level impacts in these endangered dry forests.

Based on these findings I strongly recommend greater research into the management of this invasive species as well as restoration of degraded habitats. If this invasion is not dealt with at the earliest, these forests, and their wildlife may be irrevocably damaged. The effective conservation of this ecosystem, therefore, hinges on timely and science-based management action, together with greater understanding of the ecology and ecological impacts of the invasions and increased awareness among the conservation community, forest management authorities and local forest-dependent communities.

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