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Conservation Priority of Indian Tropical Dry Deciduous Habitat: Case Study in Panna Based on Potential Regeneration of Tree Species

Talat Parveen
Department of Wildlife Sciences, Aligarh Muslim University, Aligarh-202 002, India
E-mail: talatparveen09@gmail.com

Abstract: The Panna Tiger Reserve's conservation efforts serve as an excellent example of sustainable wildlife conservation. Therefore, to better understand the features of tropical dry deciduous forests of PTR, various metrics were used, such as species density and regeneration status of different tree species. The findings indicate that 19 tree species were designated as good regenerators, while 36.956 percent of tree species were deemed non-regenerative . PCA and Multiple Linear Regression (MLR) studies were utilized to find the relationship between the different life forms of plants and the predictor or environmental variables. The PCA-MLR Model predicted tree, seedling, and sapling density accurately and revealed that shrub density, shrub cover, and disturbance variables such as lopping, cutting, cattle dung, and grazing were the most important contributors to lowering tree density. In addition, shrub density, shrub cover, and cattle dung were the most important elements influencing seedling density, whereas herb density, grass density, tree cover (%), and height were the most important factors influencing sapling density.

Keywords: Principal component analysis, Panna Tiger Reserve, Tropical dry deciduous forest, Regeneration

The tropical forest is a remarkable and diverse environment, both ecologically and genetically, covering almost half of all forest areas. It offers a range of environmental benefits and supporting the livelihoods of millions of people worldwide (Cunningham et al., 2008, Waeber et al., 2012). However, these forests are increasingly facing anthropogenic disturbances that threaten their survival. Unsustainable practices such as farmland conversion, over-harvesting of valuable wood species, and the burning of forests have led to habitat fragmentation, forest depletion, and changes in rejuvenation patterns (Menaut et al., 1995, Saha and Howe 2003). This degradation of the world's dry forests has severe implications for the environment, society, and economy. Forests exhibit notable phenological adaptations, such as distinct leaf features ranging from evergreen to deciduous leaf habits (Sandquist and Cordell 2007). In India, tropical dry forests cover a significant portion, up to 60%, of the country's forested land (Waeber et al., 2012). Among these, tropical dry deciduous forests represent approximately 40% of the total tropical dry forest area (ISFR 2019). This underscores the ecological importance of tropical dry forests in the Indian subcontinent. Numerous studies have highlighted the deteriorating condition of these ecosystems, emphasizing the need for urgent conservation efforts. (García-Cervigón 2017, Lindenmayer et al., 2017, Sambe et al., (2018), Temperton et al., 2019, Etter et al., 2020, Pratzer2021, Buchadas et al., 2022, Liu et al., 2022). The study aimed to provide a basic understanding of species density and the interaction between the environment and the forest community of the Panna tiger reserve.

MATERIAL AND METHODS

Study area: The Panna Tiger Reserve in northern Madhya Pradesh's Vindhaya Hill is a more delicate environment for Tigers. It is located in the districts of Panna and Chattarpur in Madhya Pradesh. It is controlled as the core area and covers an area of roughly 576.12 square kilometers. The Tiger Reserve has six forest typessouthern tropical dry deciduous teak forest, northern tropical dry deciduous mixed forest, dry deciduous scrub forest, *Anogeissus pendula* forest, *Boswellia* forest, and dry bamboo brakes. This forest is dominated by a broad plateau and gorges. The Ken River, which has become a lifeline for the reserve and also generates waterfalls on its route to the valley, distinguishes the woodland (Fig. 1).

Data collection: A stratified random sampling approach was implemented for conducting extensive vegetation sampling in the area. This method involved the use of the lowest administrative unit, the forest beat, for stratification purposes. A total of 34 line transects were established, covering the entire area of the tiger reserve's 34 beats. The survey of 338 plots provided comprehensive coverage of 10.6132 hectares of forest land.The transect, which was two kilometers long and segmented into 200 parts, was used at each sample plot. A circular plot with a radius of 10 meters was used, which contained nested 5-meter-radius plots. The density of tree species was determined using a 10-meter-radius circular plot, while a nested 5-meter-radius circular plot was employed to estimate the number of shrubs, seedlings and saplings. The density of grasses and herbs was measured in four 0.5x0.5m quadrants at four random places inside a 10m circular plot.

The tree cover was measured using a gridded mirror, while the shrub cover was estimated visually. Ground cover, including herb cover (%), grass cover (%), bare ground (%), withered stone (%), litter (%), and rock (%), was recorded using the Point-intercept method. Additionally, signs of human activity, such as animal grazing, were noted within a 10 m radius of each sampling plot. Geographic information system (GIS) tools were used to determine the distance to the nearest water body, forest road, and human habitation. Topographic features like altitude, slope, and aspect were obtained using a digital elevation model.

Data Analysis

Density: The number of the tree species and their regenerating species (seedling and sapling) was estimated as “number of individuals/ ha”.

Density = number of individuals of the species / area (ha)

Regeneration status: The forest's regeneration was measured according to Shankar (2001) and Singh et al. (2017) using the following criteria.

I. Good if the density of Seedlings> Saplings>Trees

II. Fair if the density of Seedling>Sapling<Trees

III. Poor if the species present only in the sapling stage but not in the seedling stage.

IV. Not regenerating if the species is absent in both seedling and sapling stages but only found as an adult tree

Canonical correspondence analysis (CCA): The study used CCA direct ordination to analyze the corelation and regression between floristic data and habitat variables (Ter Braak and Prentice 1988, Kent and Coker 1992).

Principal component analysis (PCA): The original variables are weighted linear combinations of the principal components. The Kaiser-Meyer Olkin (KMO) and Bartlett's test measures of sample adequacy were utilized to validate the applicability of PCA to the data. VARIMAX rotation approach was also used to maximize the difference in factor loading on each principal component (Terdalkar and Pai 2001).

Multiple linear regression (MLR): To identify the best predictors of plant communities, conducted multiple linear regression analysis of various plant life forms, such as trees, seedlings, and saplings, using stepwise variable selection processes on the principal component scores.

Statistical analysis: The square root and arcsine transformations were applied before conducting multivariate analysis. SPSS version 7.5 and Past 3.1 software (version 3.1, Øyvind Hammer, Natural History Museum, University of Oslo) were used for all analyses.

RESULTS AND DISCUSSION

Canonical correspondence analysis (CCA): The direct gradient analysis using CCA was employed to examine the relationship between environmental factors and tree species composition in five distinct habitats (Fig. 2). Monte Carlo

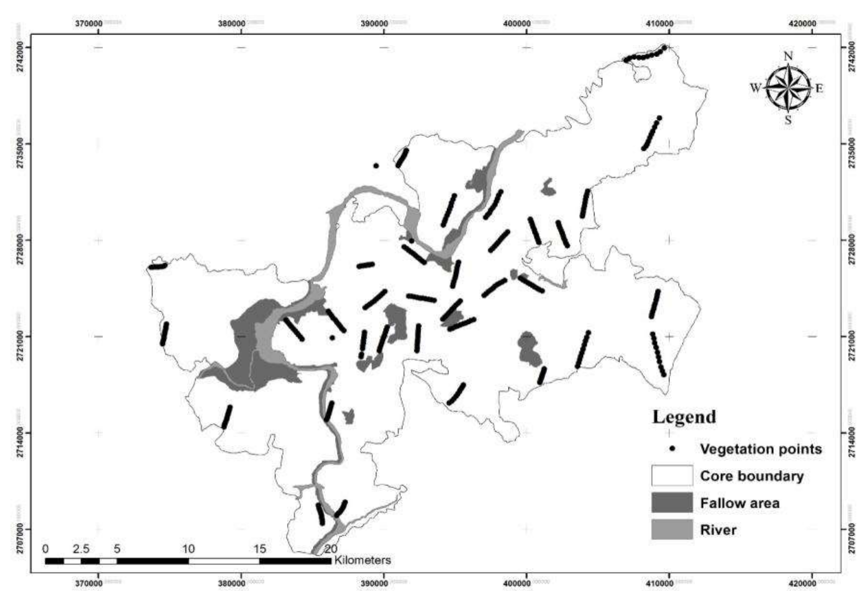

Fig. 1. Vegetation points along the transects

permutation test (100 iterations) indicated a lack of significant correlation between species abundance and the supplied environmental variables. The four axes (eigenvalue, axis 1= 0.433, axis 2= 0.169, axis 3= 0.091 and axis 4= 0.048) of the CCA ordination analysis explained 58.35, 22.84, 12.3, and 6.50% of the variance in tree species assemblages with the predictive variables (Table 2). In the mixed-thorn habitat, the species *Zizyphus xylopyra*, *Phyllanthus emblica*, and *Pterocarpus marsupium* exhibited a strong correlation with positive scores on axis 4, while *Tectonagrandis* demonstrated a moderate correlation with a positive score on axis 4. The proximity to a water body and disturbance factors such as tree cutting and cattle dung emerged as significant predictors for these tree species.

In the habitat characterized by a mix of thorny vegetation, the plant species *Zizyphus xylopyra*, *Phyllanthus emblica*, and *Pterocarpus marsupium* displayed a noteworthy strong correlation with positive scores on axis 4. Similarly, *Tectona grandis* demonstrated a moderate correlation with a positive score on axis 4. Moreover, the proximity to a water body and the presence of disturbance factors such as tree cutting and cattle dung were identified as influential predictors for the distribution of these tree species. The species *Butea monosperma* and *Acacia catechu* were observed in the lower right quadrant. These species strongly correlated with the Mixed-thorn habitat on the second axis. This correlation was predicted by lower tree height, tree GBH (Girth at Breast Height), shrub cover percentage, and tree cover percentage (Table 2, Fig. 2).

The positive scores on axis 2, specifically in the upper left quadrant, predominantly comprised *Wrightia tinctoria*, *Lagerstroemia parviflora*, and *Boswellia serrata*. In the mixed habitat type, other significant disturbance gradients included the lopping of trees, grazing, percentage of grass cover, percentage of herb cover, as well as grass and herb density. The teak-mixed habitat in the lower left included a stunning array of trees such as *Buchanania lanzan*, *Ceriscoides turgida*, *Scheichera trijuga*, *Balanites aegyptiaca*, *Diospyros melanoxylon*, *Terminalia bellirica*, *Limonia acidissima*, *Careya arborea*, and *Adina cordifolia*. These trees showed a positive correlation with shrub density and cover percentage in the teak-mixed habitat on axis 3. However, *Holoptelea integrifolia*, *Abrus precatorius*, *Albizzia procera*, and *Bombax ceiba* exhibited a negative correlation with both shrub density and shrub cover in the teak-mixed habitat. *Aegle marmelos* and *Terminalia bellirica* were situated in the lower right axis. These species exhibited a stronger correlation with the teak-mixed habitat along axis 3, while demonstrating a negative association with tree GBH, tree density and tree cover (%).

In the mixed with dense understory, certain tree species such as *Stephegyne parvifolia*, *Bassia latifolia*, and *Bauhinia racemose* exhibited a negative correlation with tree cover (%), shrub cover (%), higher tree density, tree height, tree GBH, and slope, while showing a positive correlation with herb density and grass density on axis 2. Additionally, in the Kardhai-mixed habitat, species including *Anogeissus pendula*, *Cassia fistula*, *Terminalia arjuna*, *Gardenia latifolia*, and *Acacia latifolia* demonstrated a positive relationship with altitude, distance near human habitation, and slope.

Density and status of regeneration: The study carried out within a 2.653-hectare area on density of trees and the regeneration density of seedlings and saplings (Table 1). The

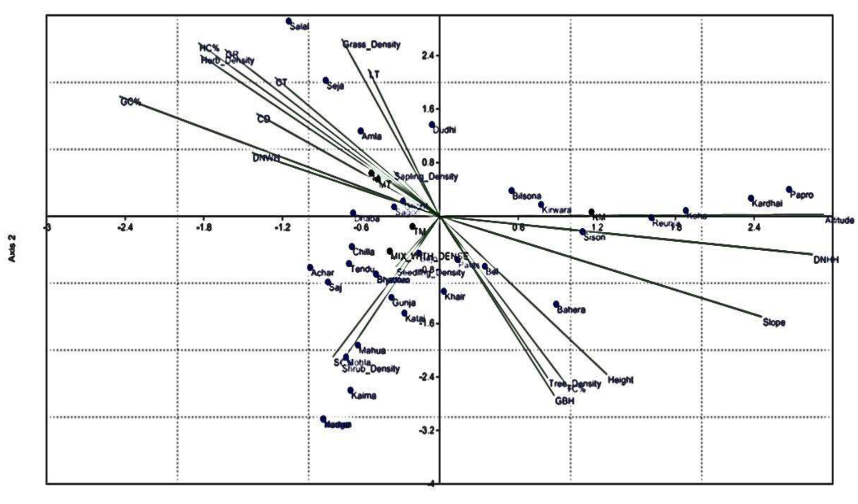

Fig. 2. Canonical correspondence analysis (CCA) ordination diagram, showing the influence of predictive factors on tree- species assemblages in each habitat (A). winter (B). summer. Arrow symbolize the predictive factors. Habitat codes represent the following: *TM* Teak-mixed; *MT* Mixed-thorn; *M* Mixed; *KM* Kardhai-mixed; *Mix with Dense* Mixed with dense understory

Table 1. Regeneration density and status of tree species in Panna tiger reserve

Species	Tree (Individual ha^{-1})	Seedling (Individual ha^{-1})	Sapling (Individual ha^{-1})	Regeneration status
Aegle marmelos	14.227	7.349	13.662	Good
Anogeissus latifolia	15.546	0.659	0.094	Good
Abrus precatorius	13.944	0	0	Non-regenerating
Adina cordifolia	0.376	0	0	Non-regenerating
Anogeissus pendula	11.306	4.711	3.580	Good
Acacia catechu	22.990	1.507	1.224	Good
Acacia latifolia	1.130	0.188	0.188	Good
Allangium salvifolium	0.753	0.094	0	Fair
Albizzia procera	0	0.848	0.188	Good
Azadirachta indica	0.188	0.282	0.282	Good
Balanites aegyptiaca	4.334	1.978	1.413	Good
Bassia latifolia	1.884	0.188	0	Fair
Bauhinia racemosa	2.355	0.753	0.848	Good
Butea monosperma	5.182	0.188	0.848	Good
Boswellia serrata	1.790	0	0	Non-regenerating
Bombax ceiba	0.565	0.094	0	Fair
Buchanania lanzan	0.848	0.188	0	Fair
Ceriscoides turgida	0.376	1.978	0.565	Good
Cassia fistula	2.167	0.659	1.884	Good
Careya arborea	0.094	0	0	Non-regenerating
Diospyros melanoxylon	13.944	16.206	10.647	Good
Euginea jambolana	0.942	3.109	2.826	Good
Feronia elephantum	0.376	0	0.942	Poor
Ficus infectoria	0.471	0	0	Non-regenerating
Ficus benghalensis	0.094	0	0	Non-regenerating
Ficus religiosa	0.188	0	0	Non-regenerating
Gmelina arborea	0.282	0	0.094	Poor
Holoptelea integrifolia	0.094	0	0.094	Poor
Limonia acidissima	1.507	3.015	3.768	Good
Lannea coromandelica	0.188	0	0	Non-regenerating
Lagerstroemia parviflora	18.656	2.544	6.124	Good
Moringa oleifera	0.094	0	0	Non-regenerating
Mangifera indica	0.188	0	0	Non-regenerating
Phyllanthus emblica	2.449	0.094	0	Fair
Pterocarpus marsupium	0.094	0	0	Non-regenerating
Stephegyne parvifolia	2.167	0	0.471	Poor
Saccopetalum tomentosum	1.413	0	0	Non-regenerating
Sterculia urens	0.471	0	0	Non-regenerating
Schleichera trijuga	0.188	0	0	Non-regenerating
Soymida febrifuga	0.376	0	0	Non-regenerating
Tamarindus indica	0.094	0	0	Non-regenerating
Terminalia arjuna	0.942	0.094	0	Fair
Tectona grandis	56.533	5.276	19.032	Good
Terminalia tomentosa	1.696	1.319	0	Fair
Terminalia bellirica	0.565	0	0	Non-regenerating
Wrightia tintoria	1.507	6.784	11.118	Good
Zizyphus xylopyra	19.692	10.081	8.951	Good
Total	225.280	70.288	89.038	

Tectona grandis had the highest species density, with 56.53 individuals per hectare, indicating a rich presence of this species in the area followed by *Acacia catechuZizyphus xylopyra*, *Lagerstroemia parviflora*, *Anogeissus latifolia*, and *Aegle marmelosa. Moringa oleifera*, *Ficus benghalensis*, *Pterocarpus marsupium*, *Holoptelea integrifolia*, and *Careya arborea* exhibited the lowest species density, each with only 0.094 individuals per hectare.The seedling density was significantly lower than in previous studies carried out in the tropical dry deciduous forest (Pawar et al., 2012, Bargali et al., 2014, Kothadaraman and Sundarapandian 2017, Phongoudome et al., 2012). The density of saplings was also lower when compared with findings from previous research (Bargali et al.,2014 , Phongoudome et al., 2012). This discrepancy underscores a significant reduction in forest regeneration. The number of young trees within a certain area directly shows how the local environment affects forest density.

Nineteen species demonstrated robust regenerative capabilities, successfully establishing themselves as trees, seedlings, and saplings. These species collectively represented 41.304 percent of all tree species. The *Diospyros melanoxylon* and *Tectona grandis*, exhibited superior regenerative capacities within this locale. The significant portion of tree species (15.217 percent) observed in tree and seedling stages, were categorized as having fair status. Additionally, 36.956 percent of tree species were identified as challenging to establish within the community, as they were exclusively represented in adult or tree stages, rendering them non-regenerative.The four tree species – *Holoptelea integrifolia*, *Stephegyne parviflora*, *Feronia elephantum*, and *Gmelina arborea* were identified as poor regenerators. They were only found in tree and sapling forms, not as seedlings. These findings could help policymakers make well-informed decisions regarding selecting and managing tree species within the

Table 2. CCA axis lengths of tree-species showing the level of correlation between CCA scores and environmental factors. (Eigen value and % variance of species-environment relationship)

	Tree			
	Axis 1	Axis 2	Axis 3	Axis 4
Canonical eigen value	0.44^{ns}	0.17^{ns}	0.091	0.048
Cumulative % variance	58.36%	22.85%	12.3%	6.50%
Correlation coefficient				
Slope	0.820	-0.500	0.413	-0.100
Height	0.425	-0.788	0.108	-0.707
GBH	0.291	-0.892	-0.009	-0.598
Tree density	0.275	-0.806	-0.083	-0.704
Seedling density	-0.111	-0.252	0.059	-0.960
Sapling density	-0.117	-0.224	-0.710	-0.442
Shrub density	-0.250	-0.732	0.534	-0.137
Herb density	-0.609	0.803	-0.326	0.372
Grass density	-0.248	0.882	-0.428	0.364
Shrub cover%	-0.271	-0.701	0.568	-0.191
Tree cover%	0.320	-0.832	-0.149	-0.639
DNWH	-0.477	0.317	0.256	0.823
Altitude	0.978	0.007	-0.067	-0.127
CT	-0.419	0.693	-0.128	0.801
LT	-0.182	0.732	0.477	-0.419
CD	-0.466	0.510	0.201	0.810
GR	-0.547	0.830	-0.124	0.562
Herb cover%	-0.613	0.862	-0.159	0.313
Grass cover%	-0.814	0.596	-0.345	0.214
DNHH	0.949	-0.189	-0.253	0.104

DNWH= Distance near to waterbody; DNHH= Distance near to human habitation; CT= cutting tree; LT= Lopping tree; CD= Cattle dung; GR= Grazing; ns= Not significant community. After conducting comprehensive CCA, occurrence of specific non-regenerating tree species, specifically *Scheichera trijuga*, *Careya arborea*, *Adina cordifolia*, *Holoptelea integrifolia*, *Abrus precatorius*, *Stephegyne parvifolia*, and *Terminalia bellirica*, were negatively correlated with both the presence of shrub cover and tree cover.

The forest encompasses a diverse range of commercially valuable tree species. Indigenous communities residing within or in close proximity to these forested areas depend on these tree species for their sustenance. The leaves of *Diospyros melanoxylon*, fruits of *Eugenia jambolana*, *Ficus* spp, *Terminalia bellirica*, and *Bassia latifolia* flowers are harvested during May and June. However, potential repercussions of the prolonged harvesting of these invaluable tree speciesmay impede their regrowth and contribute to a decline in forest cover and biodiversity.

Principal Component Analysis

Trees: The PCA was used to examine 17 environmental parameters across 338 plots with the aim of identifying critical environmental factors that support varying tree species density.

The dataset of this study successfully passed the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity, indicating the suitability of conducting PCA ($F_{2,136}$ = 1014.81, P<0.001). The PCA ordination results indicate that three principal components with an eigenvalue loading greater than 1 were extracted, explaining 36.14 percent of the total variance in the original dataset (Table 3). The first principal component (PC1), associated with habitats exhibiting higher frequencies of lopping trees, chopping trees, and increased cattle grazing, displayed a positive correlation with disturbance variables, explaining 14.81 percent of the variance. The second principal component (PC 2) demonstrated a positive relationship with herb and grass density, whereas the third principal component (PC 3) showed a positive association with shrub density and shrub cover, suggesting that there was a significant vertical stratification impact.

Seedling and sapling: The loading plot of the rotated

Table 3. Principal component analysis of environmental variables for tree, seedling and sapling density

	Tree density			Seedling density			Sapling density		
	PC 1	PC 2	PC 3	PC 1	PC 2	PC 3	PC 1	PC 2	PC 3
Eigen Value	2.52	1.86	1.78	3.01	2.09	1.84	2.93	2.08	1.87
Variance (%)	14.81	10.91	10.42	17.67	12.24	10.79	17.61	12.18	10.95
Cumulative variance (%)	14.81	25.71	36.13	17.67	29.89	40.69	17.61	29.78	40.72
Variables									
Shrub Density	-4.26×10^{-2}	-4.10×10^{-2}	**0.918**	-0.326	**0.790**	0.120	-0.339	0.133	**0.694**
Herb Density	5.04×10^{-3}	**0.891**	1.641×10^{-2}	-0.157	-0.100	**0.765**	-0.249	**0.682**	0.185
Grass Density	-2.25×10^{-2}	**0.886**	7.121×10^{-2}	-0.290	-0.242	**0.773**	-0.109	**0.787**	1.98×10^{-2}
Herb Cover (%)	0.122	-8.37×10^{-2}	-5.14×10^{-3}	0.279	0.369	-0.108	0.140	-0.238	0.234
Grass Cover (%)	-5.37×10^{-2}	1.52×10^{-2}	4.970×10^{-2}	-0.139	-0.151	8.929× 10-2	-0.210	0.262	-0.431
Shrub Cover (%)	-0.118	0.127	**0.909**	-0.436	**0.672**	0.367	-0.430	0.241	**0.710**
Tree Cover (%)	-3.84×10^{-2}	-0.287	0.161	7.342×10^{-2}	0.427	-0.475	2.827×10^{-2}	-0.630	0.281
Altitude	-3.16×10^{-2}	0.104	8.792×10^{-2}	8.074×10^{-2}	0.124	**0.524**	0.147	0.445	4.366×10^{-2}
Slope (%)	8.557×10^{-2}	-1.58×10^{-2}	-2.75×10^{-2}	-4.07×10^{-2}	-0.325	8.144 ×10-2	-2.45×10^{-2}	9.835×10^{-2}	-0.337
DNWH	0.247	1.031×10^{-2}	4.462×10^{-2}	0.369	0.314	0.207	0.492	-8.03×10^{-2}	0.427
DNHH	-0.109	9.872×10^{-2}	7.574×10^{-2}	-0.461	-8.74 ×10-2	8.849× 10-2	-0.341	9.256×10^{-2}	-0.349
Aspect	-0.170	0.212	8.661×10^{-2}	-0.234	0.185	7.512 ×10-2	-0.220	-0.185	7.434×10^{-2}
Cutting Tree	**0.648**	2.064×10^{-3}	-2.10×10^{-2}	**0.719**	0.197	0.179	**0.745**	0.157	0.164
Lopping Tree	**0.801**	4.496×10^{-2}	4.768×10^{-2}	**0.787**	0.111	0.293	**0.763**	0.178	0.202
Cattle Dung	**0.721**	-4.21×10^{-2}	-0.190	**0.659**	-0.168	9.636 ×10-2	**0.722**	0.117	-0.155
Grazing	**0.703**	-3.88×10^{-2}	-5.62×10^{-2}	**0.695**	8.433× 10-2	0.198	**0.669**	0.200	-5.792×10^{-2}
Fire	-1.78×10^{-2}	-0.139	-9.66×10^{-2}	0.167	-2.32 ×10-2	2.225 ×10-2	0.139	$5.499\ 10^{-2}$	3.090×10^{-2}

DNWH= Distance Near Waterbody, DNHH= Distance Near Human Habitation.
Bold letter indicates higher correlation between variables and its corresponding principal component

principal components revealed the recovery of three components with an eigenvalue loading of one, collectively explaining 40.7 percent of the total variance in the seedling dataset (Table 3). The second principal component (PC 2) in the multivariate analysis showed a substantial loading of 2.09 eigen values, explaining approximately 12.24% of the total variance. This component demonstrated a strong association with shrub density and shrub cover, which were positively correlated. Furthermore, the third principal component (PC 3) explained 10.79% of the total variance, with two environmental factors showing significant positive associations with this component.In the sapling data set, four environmental variables exhibited a strong positive correlation and significantly contributed to the loading of the first principal component (PC1). These variables, indicative of disturbance, collectively represented an eigen value loading of 3.003 and accounted for 17.67 percent of the total variance (Table 3). In the primary component (PC 1), all disturbance variables in the sapling data set demonstrated a positive correlation, responsible for 17.61% of the total variance. Furthermore, two environmental variables exhibited a positive correlation with the second primary component (PC 2), while another variable showed a negative correlation. Herb density, grass density, and tree cover (%) contributed 12.18% to the overall variance. The third principal component (PC 3) positively and significantly correlated with biotic factors such as shrub density and shrub cover.

Multiple Linear Regression

Trees: The study utilized Multiple Linear Regression to identify the optimal linear combination of Principal Component (PC) scores for the prediction of tree density.

In the analysis, Model 1 demonstrated an ability to account for 55% of the variability in tree density, as indicated by the corrected R^2 value of 0.55. Specifically, in Model 1, where the principal component score was utilized as the independent variable, it was observed that only PC 3 was selected as a significant factor in explaining the variability in tree density (R = 0.397). This finding suggests that tree density could be effectively predicted using only PC 3 as a predictor in Model 1.

Tree density 1 = 15.700 – 0.626 (PC 3)

Considering the correlation coefficient of PC 3 in model 1 and the associated PCA outcomes, which indicate a strong correlation between PC 3 and two specific variables, it is reasonable to infer that a reduction in both shrub density and shrub cover will correspond to an increase in tree density.The adjusted R^2 score of 0.80 for Model 2 indicates its ability to account for 80% of the variation in tree density. In contrast to Model 1, both PC 3 and PC 1 significantly contribute to the explanation of tree density ($P<0.01$, R = 0.430). Moreover, in Model 2, PC 1 emerges as a crucial factor in replicating tree density. The final Model 2 is described as follows (Table 4):

Tree density 2 = 15.700 - 0.626 (PC 3) – 0.401 (PC 1)

The model provided accurate predictions regarding tree density while elucidating the environmental factors influencing it. Shrub density, shrub cover, and various forms of disturbance emerged as the primary ecological variables impacting tree density within the studied area. Notably, these variables exhibited a clear inverse relationship.

Table 4. Results of regression analysis for tree, seedling and sapling density

Independent variables	Regression coefficient		Standard coefficient	t	P	Tolerance	VIF	Adjusted R^2
Tree density								
	B	Std. error	B					
Constant	15.71	0.293		53.54	0.000			
PC 3	-0.626	0.294	0.416	8.11	0.000	1.000	1.000	0.55
Constant	15.71	0.292		53.54	0.000			
PC 3	-0.646	0.292	0.420	8.22	0.000	0.999	1.001	0.80
PC 1	-0.401	0.292	-0.109	-2.15	0.033	0.999	1.001	
Seedling density								
Constant	20.15	0.802		28.88	0.000			
PC 2	-2.67	0.804	-0.250	-3.33	0.001	1.000	1.000	0.57
Sapling density								
Constant	23.54	0.779		30.19	0.000			
PC 2	-2.55	0.782	-0.236	-3.26	0.001	1.000	1.000	0.44

Aegle marmelos and *Wrightia tinctoria*, two of the top five seedling and sapling species, failed to establish themselves as dominant adult tree species. *Wrightia tinctoria* exhibited higher prevalence in disturbed areas receiving direct sunlight, whereas *Aegle marmelos* displayed associations with areas characterized by dense canopies. The species *Wrightia tinctoria*, *Phyllanthus emblica*, *Ceriscoides turgida*, *Acacia catechu*, and *Lagerstroemia parviflora* were demonstrated an association with disturbance gradients, such as the presence of cattle dung and lopped trees. These disturbances lead to an increased exposure to direct sunlight due to the openness of the Mixed habitat type.The forest peripheries, where *Lagerstroemia parviflora* and *Butea monosperma* were prevalent, exhibited distinct environmental conditions. These areas experienced higher air temperatures, reduced humidity, and lower soil moisture levels compared to the forest interior. These conditions create an environment conducive to the growth of species that depend on ample light for their development (Chazdon et al., 1998, Marod et al., 2010, Fayiah et al., 2018). *Lagerstroemia parviflora* possesses a remarkable capability to produce a wide range of seeds within a single individual, contributing to its successful germination across diverse environmental conditions (Shukla and Ramakrishnan 1981). This inherent adaptability has rendered *Lagerstroemia parviflora* well-suited to thrive in the unique conditions of forest edges, making it an intriguing subject for further research and study.In contrast, *Diospyros melanoxylon* was identified as the tree species with the highest germination rate, and it can tolerate higher shrub cover percentages. Khurana and Singh (2000) have observed a unique biological feature of *Diospyros melanoxylon*. This feature allows the species to delay the germination process until the following rainy season if there is insufficient soil moisture during initial germination. This adaptation enables the species to survive and thrive in fluctuating environmental conditions.

Seedling: The principal component scores significantly affected seedling density. The significant value of PC 2 was less than 0.05, indicating significance and influence on seedling density. Moreover, the modified R^2 value of 0.57 suggests that the independent variables explain 57% of the dependent variable, seedling density. The multiple regression equation is as follows (Table 4):

Seedling density = 20.15 – 2.669 (PC 2)

Principal Component 2 (PC 2) showed a statistically significant relationship with both shrub density and shrub cover. this component exhibited a negative correlation with these variables. The highest shrub density was recorded for *Lantana camara*, which is categorized as alien weeds (Fig. 3). In addition, the analysis of land use and land cover revealed that the predominant habitat type within the Tiger reserve area was classified as mixed with dense understory. The understory of this habitat type was explicitly characterized by the dense presence of *Lantana camara*. The adaptability of *Lantana* was also observed across various habitat types, including Teak-mixed, Mixed, and Kardhai-mixed, except the Mixed-thorn habitat. This versatile invader may potentially impede the natural regeneration of native trees, ultimately leading to a decline in both tree diversity and the overall structural integrity of the ecosystem. The *Lantana* invasion has been the subject of extensive research due to its significant impact on the vegetation structure of ecosystems. Previous studies have highlighted that the presence of *Lantana* can induce alterations in soil properties and the hydrology of the affected area. This specific study conducted an assessment and determined that the density of *Lantana* in the area was estimated at 754 individuals per hectare, aligning closely with the broader range of 1500-3000 individuals per hectare typically observed in tropical and sub-tropical forested regions (Joshi 2002).

Sapling: The resultant adjusted R^2 value was calculated to be 0.44, signifying that the model can elucidate 44% of the variance in sapling density. Within the regression model, only PC 2 was identified as a significant explanatory variable for the fluctuations in sapling density ($P<0.01$, $R = 0.236$). The ensuing multiple regression equation is as follows (Table 4):

Sapling density = 23.536 – 2.542 (PC 2)

PC 2 is strongly associated with three specific factors: herb density, grass density, and Tree Cover (%). Even though these variables were have negative relationships, an increase might lead to a decrease in sapling density. The comparative analysis was conducted in 338 plots within the Panna Tiger Reserve to assess the mean density (ha) of the alien weed *Hyptis suaveolens* in relation to native herb species (Fig. 4). This invasive species poses a threat to the local vegetation community (Sharma et al., 2007). The estimated density of *H. suaveolens* was 14906 individuals per hectare. The highest herb density was observed in the Mixed and Mixed-thorn habitat types. Moreover, the species was found near the Gangau B and Naranan beats.The maximum height of *H. suaveolens* typically ranges from 0.5 to 1.5 meters. However, during the growing season reach up to 2.5 meters.Their investigation revealed that *H. suaveolens* exhibited maximum presence in grass-dominated areas, potentially leading to a reduction in grass abundance and subsequently diminishing the available food resources for animal species, particularly small-sized antelopes. Additionally, the study observed that *Hyptis suaveolens* also provides cover for the Four-horned Antelope. These

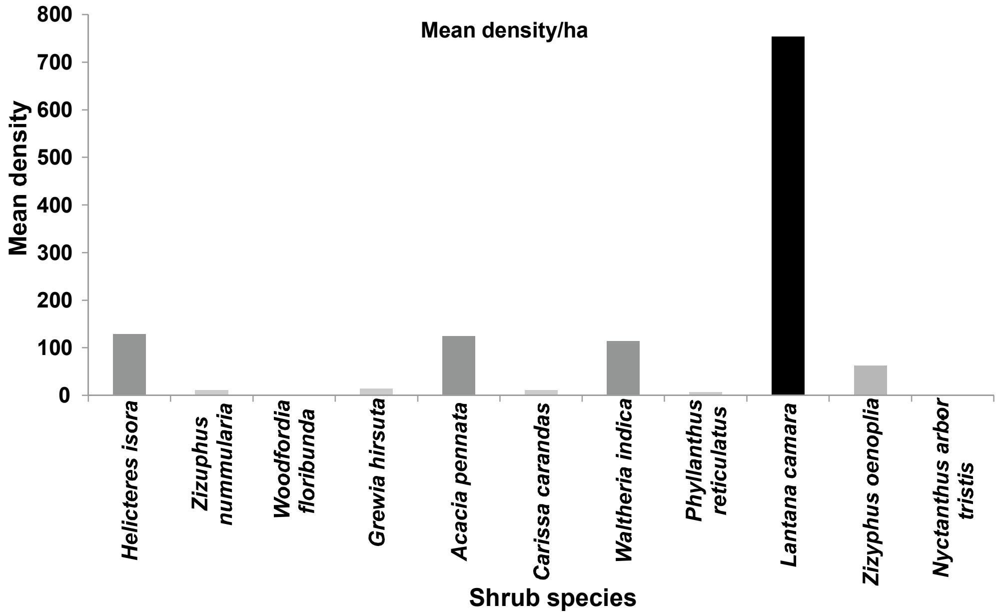

Fig. 3. Mean density (ha) of *Lantana camara*, the alien weed, compared to native shrub species in Panna Tiger Reserve

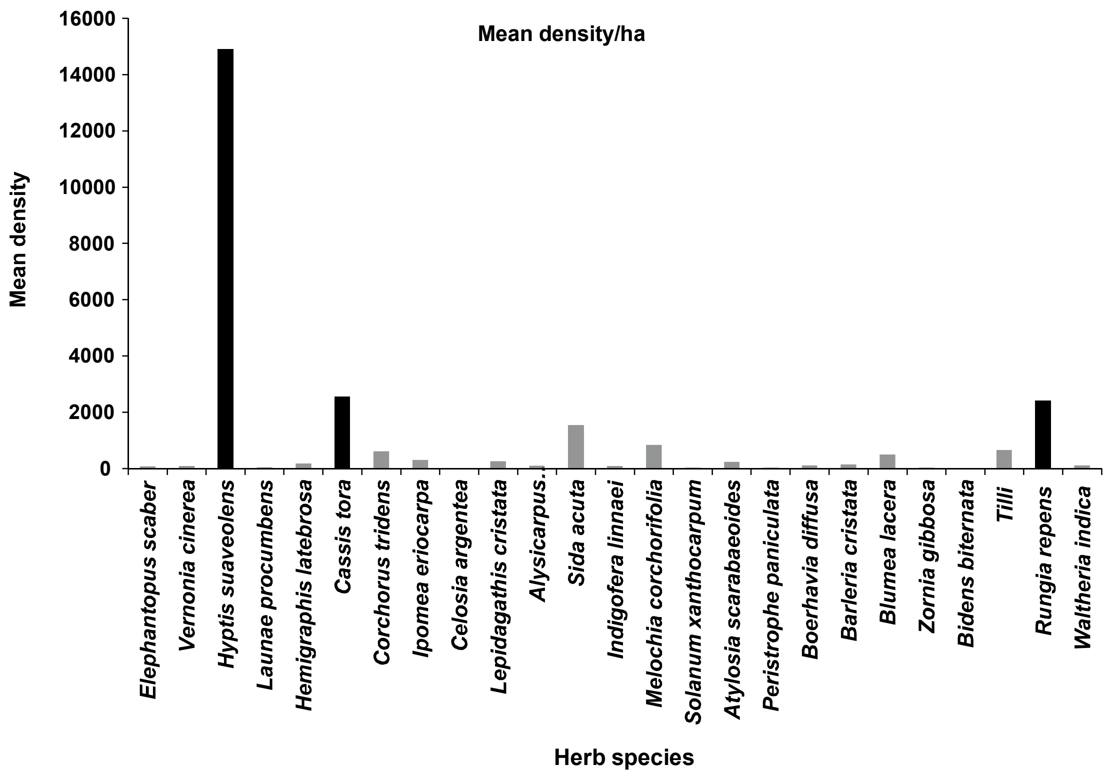

Fig. 4. Mean density (ha) of *Hyptis suaveolens*, the alien weed, compared to native herb species in Panna Tiger Reserve

variables exert significant influence on the process of seed germination and subsequent survival for these particular species. Therefore, it is paramount to incorporate these species into the examination of local ecology. It is important to note that these factors possess the potential to precipitate the local extinction of certain species. Consequently, in-depth investigations of the local ecology should comprehensively address these factors to ensure the preservation of endangered species.

CONCLUSION

The study indicates that the woodland area is at risk of deteriorating into degraded savanna grassland within the coming year. To protect tree species and maintain the region's biodiversity, it is vital to take constructive steps to address these challenges. The research findings also highlight the significant role of *Tectona grandis* in maintaining the ecological balance of the Teak-mixed habitat. In the study area, the unique conditions under the teak canopy supported the successful germination and growth of seedlings of *Aegle marmelos*, *Bassis latifolia*, *Bauhinia racemosa*, *Gardenia latifolia*, *Tectona grandis*, and *Albizzia procerain*. The preservation of this species is crucial not only for its own survival but also for the overall well-being and survival of other species that depend on this specific habitat.The results of this study are significant, as they can be used to bolster the relative importance of Panna Tiger Reserve in regional and local conservation planning. Specifically, these findings can help inform the development of targeted restoration techniques and identify forest communities that require protection.

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