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Vegetation composition and plant diversity in mining disturbed tropical thorn forest of Asola-Bhatti Wildlife Sanctuary, Northern India

Vandana SHARMA[1], Smita CHAUDHRY[2,*]

1. Deen Dayal Upadhyaya College, University of Delhi, Delhi - 110078, India.
2. Institute of Environmental Studies, Kurukshetra University, Kurukshetra-136119, India.
[*]Corresponding author's phone: +91-1744- 238 404; e-mail: smita.chaudhry11@gmail.com

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ABSTRACT: Assessing the biological diversity of any region is a fundamental necessity towards promoting sustainable development and implementation as efficient conservation action plan. Thorn forests, which exhibit extreme deciduous traits, cover 1.97% of the area of India. Asola-Bhatti Wildlife Sanctuary (ABWLS), encompassing about 32.71 km^2 area, represents a typical tropical thorn forest ecosystem of low hills layered with quartzite and has undergone drastic transformations due to massive open cast mining of feldspar and for red sand stone. Regeneration of secondary forests has occurred in mining pits that have been quarried. In the present study vegetation composition and plant diversity were analysed in the undisturbed natural forest (UD) and secondary forests sites exposed to different intensities of disturbance resulting in the formation of regenerating secondary forests inside the mining pits (SRMP) and on mine spoils (SRMS) and disturbed secondary forest (HD) in the periphery of the sanctuary. The Normalised Difference Vegetation Index indicated that the Sanctuary experienced an uptrend in vegetation regeneration as a whole over the last 21 years. Total density, total basal area, species richness and diversity indexes showed a declining trend with the increase in disturbance intensity. The good conservation efforts in the sanctuary have resulted in considerable natural regeneration of secondary forests in the degraded habitats including pits and mine spoils but needs greater protection efforts as well as eco-development to meet the livelihood requirements of the local people.

KEY WORDS: Density, Diversity, Disturbance, Invasion, Mining, Protected Area, Secondary forest, Tropical Thorn forest.

INTRODUCTION

Vegetation is not only the main part of terrestrial ecosystems on earth (Piao and Fang, 2003; Godinez-Alvarez *et al*., 2009), but also the important medium for energy exchange, water cycle and biogeochemical cycle in terrestrial surface (Peng *et al.,* 2012). Sensitive to climate change vegetation dynamics has been recognized as one of the key issues in global change of terrestrial ecosystems (Fu *et al*., 2010; Kelly *et al*., 2011; Peng *et al*., 2012).

Forested ecosystems provide products and services that are of value to human societies (Turner and Daily, 2008; Johnson *et al.,* 2012). Studies in tropical forests suggest that the ecosystem productivity, stability, nutrient dynamics, and invasibility are influenced by plant species number and/or composition (Hooper *et al*., 2000, 2005; Levine, 2000; Naeem *et al*., 2000; Wolters *et al*., 2000; Spehn *et al*., 2005; van Ruijven and Berendse, 2005, Chaturvedi and Raghubanshi, 2014). The anthropogenic influence on the landscape is a discrete event through time that modifies landscapes, ecosystems, community, and a population structure, changing the substrata, the physical environment, and availability of resources (Roy *et al*. 2012). Efforts to restore forests on human impacted landscapes are occurring globally (Lamb *et al*., 2005; Chazdon, 2008; Johnson *et al.,* 2012). One way of increasing forest cover is to protect and manage the large areas of secondary or regrowth forests now present (Lamb *et al*., 2005). Assessing the biological diversity of any region is a fundamental necessity towards promoting sustainable development and implementation as efficient conservation action plan (Yoccoz *et al*. 2001; Magurran 2013; Mukherjee *et al*., 2017).

Consequent to mining, loss of above and below-ground biodiversity creates an extremely harsh environment which is non-conducible for regeneration of the native ecosystem (Requena *et al*., 2001) with high socio-economic value, and makes the area unfit for use of the local communities. Opencast mining of feldspar and subsequently for red sand stone in Delhi Ridge has often caused irreversible alterations in flora, fauna, hydrology, and soil biology and creation of huge overburden dumps. Therefore, abandoned mines are recognized as man-made barren sites which have become both an ecological and economic burden on society (Sharma *et al*., 2010). Assessing and monitoring the impacts of mining on ecosystems are critical to achieving goals of sustainable development. In recent decades, the understanding of vegetation dynamics has been improved by using remote-sensing techniques. The temporal resolution of remote-sensing data sets enables the study of dynamic phenomena such as post mining ecosystem recovery over a multiple-year period.

Thorn forests, which exhibit extreme deciduous traits (Murphy and Lugo, 1986), cover 1.97% of the area of India (Roy *et al*. 2012). The deleterious effects of human disturbances on the floristic structure of tropical dry forests has also been evaluated (Rai, 1985; Murphy and Lugo, 1986; Pauline *et al*., 1996; Hare *et al*., 1997; Yadav and Gupta, 2006). The details of vegetation structure, composition and distribution of Ridge forests of Delhi was studied by Naithani *et al*. (2006). However, patterns of plant species diversity, composition and structure within the natural forest and secondary forest during the post mining period after the establishment as a sanctuary have not been ever documented for Delhi Ridge forest especially Southern Ridge. Vegetation analysis of these degraded forests would help in understanding the effects of disturbance on the composition and dynamics of forest community and also would help in managing the secondary forests that regenerates after the disturbance. Hence the present study deals with the plant species diversity, structure and composition across various strata within the Asola-Bhatti Wildlife Sanctuary, a typical northern tropical thorn forest.

MATERIALS AND METHODS

Asola-Bhatti Wildlife Sanctuary (ABWLS) is a protected area located in the south-eastern part of the southern ridge in Delhi, India lies between latitude 28°24′00″ to 28°30′00″N and longitude 77°12′00″ to 77°17′00″E (Fig.1) covering an area of about 32.71 km^2 and the entire sanctuary bio-geographically represents a part of Aravalli range. Out of 543 Wildlife sanctuaries in India, the ABWLS is the only area, which represents north-eastern flat-topped hill form of country's oldest hill ranges- the Aravalli-a highly eroded remnant of Precambrian uplift. Bhatti area of the sanctuary has undergone massive open cast mining of feldspar (for preparation of high grade pottery) and subsequently for red sand stone or morrum (building material). Mining was stopped and Asola Wildlife Sanctuary (1904 Hectares) was carved in 1986 under section 18 of Wildlife (Protection) Act 1972 from the community-land of three villages namely Asola, Shurpur and Maidangarhi. In its haste to develop green cover over the entire area, the administration undertook seeding and planting of the area with several tree species, of which *Prosopis juliflora* and *Acacia* spp. have been successful. Subsequently in 1991 another notification was issued to declare Bhatti (877 Hectares) as a part of Wildlife Sanctuary.

The climate of ABWLS is typically continental which is characterized by cold winter months and hot, dry summer months (Fig. 2). Thar Desert in west and Gangetic plains in east also has their impact on climate of ABWLS. The site is heterogeneous with intermixing of hard stable rocks and red sand mounds prone to erosion. This landscape has undergone drastic transformations due to mining, replacement of natural forest with commercial plantations of exotic species and urbanization. As a result, natural habitats have fragmented and degraded causing local extinction of several species. A major disturbance factor in the area is livestock grazing and fodder collection.

The main faunal element includes Nilgai (*Boselaphus tragocamelus)*, Jungle Cat (*Felis chaus)*, Small Indian Civet (*Viverricula indica)* and Small Indian Mongoose (*Herpestes javanicus)*, Rufous Tailed hare (*Lepus nigricollis)*, Porcupine (*Hystrix indica)* and about 200 species of resident and migratory birds. Hyaena (*Hyaena hyaena*), Leopard (Panthera pardus), Wolf (*Canis lupus*), and Chinkara (*Gazella gazella*), reported in the Gazetteer of Delhi, have not been sighted after 1940. Despite its ecological importance as home to a large number of threatened and charismatic species of flora and fauna this area has been neglected in terms of ecological studies and biodiversity assessments.

Study sites

A total of 4 sites representing various categories of natural forests and secondary forests in relation to regeneration and disturbance regimes were selected for vegetation sampling: (a) Undisturbed forest site (UD) constitutes mixed natural forest, free from anthropogenic pressure that has remained protected due to socio-religious tradition of considering this area as a sacred groove; (b) Secondary forest regenerating inside the abandoned mining pits (SRMP) created from post mining operations which were under isolation period of 20 to 28 years and remained undisturbed from human interference and livestock grazing due to difficult terrain, causing regeneration. (c) Secondary forest regenerating on mine spoils of Sanctuary (SRMS) are the mounds of overburden near mining pits and are dominated by *P. juliflora*. (d) Highly Disturbed forest (HD) situated on the periphery of ABWLS is a highly disturbed area subjected to large scale tree felling and overgrazing and cropping in the valleys by the local population despite being a part of a protected forest of the state government. It has been reduced to scrub vegetation. Among the sites selected, the two study sites under consideration represent ecological conditions of two extremes; one being the highly degraded (HD) and the other relatively undisturbed forest which is well protected (UD). Details of the sites are presented in Table 1.

The four sites (UD, SRMP, SRMS and HD) showed drastic difference in density and basal area of trees. Vegetation differences also influence the soil properties in the forest floor of the respective forest sites (Table 2). The soil at all the sites was sandy loam and pH ranged from slightly acidic (UD) to highly basic (HD). Throughout the sanctuary the soil was in saline range except UD site (pH 5.94) which remained unaffected by mining activities. The salty encrustation and more visible calcium canker nodules presence in soil might be the reason behind increase in soil salinity. Soil bulk

Table 1: Description of study sites.

Study sites	Latitude	Longitude	Altitude (m)	Terrain	Vegetation
UD	28°25′05″N	77°12′55″E	288	Undulating, bouldry and rocky	Moderately dense thorn forest
SRMP	28°25′34″N	77°14′05″E	148	Rocky, bouldry, Slope towards south west	Moderately Dense thorn forest - *Prosopis* dominated
SRMS	28°25′18″N	77°13′49″E	239	Slope towards South-eastern side	Open forest *Prosopis* dominated
HD	28°25′11″N	77°14′08″E	280	Undulating Terrain	Open scrub

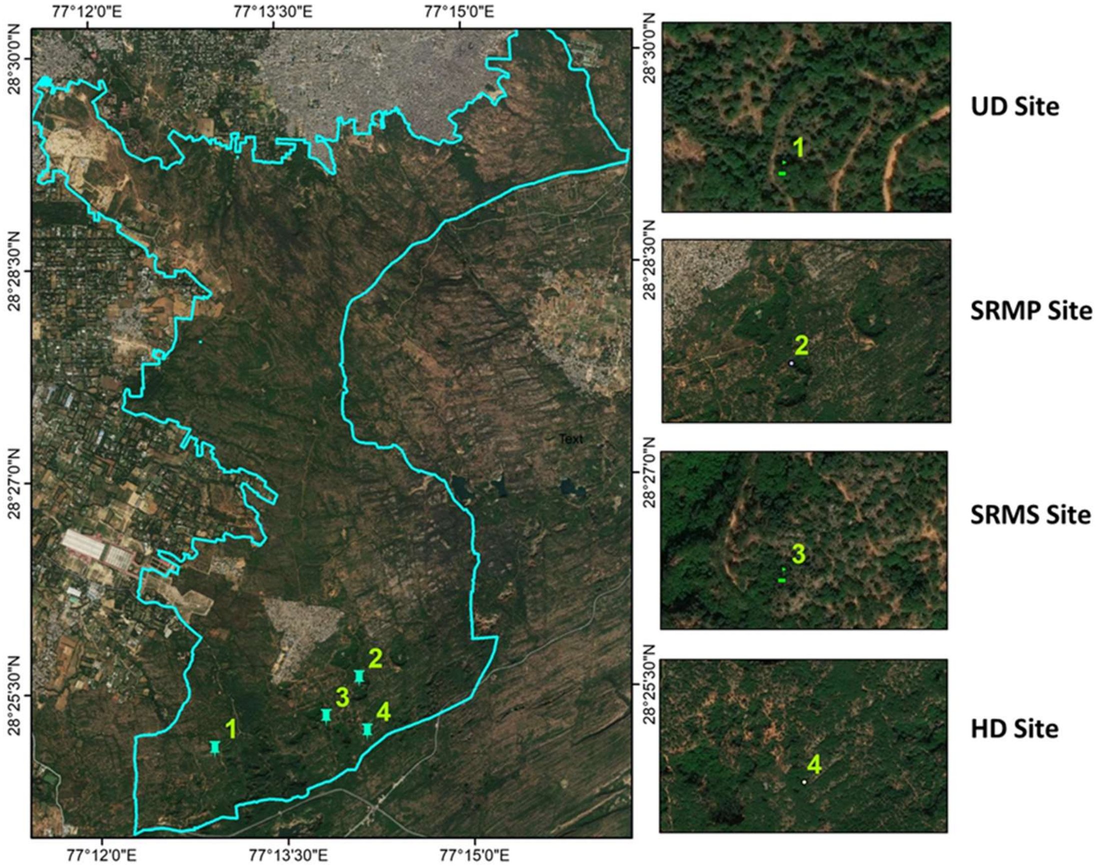

Fig. 1: Aerial view of the Asola-Bhatti Wildlife Sanctuary displaying study sites.

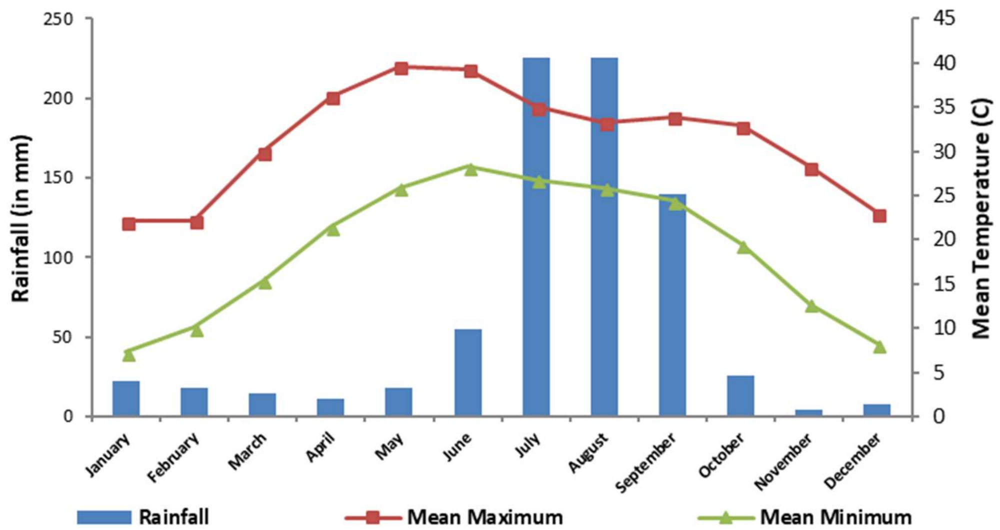

Fig 2: Climatic Diagram of Asola-Bhatti Wildlife Sanctuary for the year 2012 (Source: Indian Meteorological Department, New Delhi).

Table 2: Physico-chemical properties of top soil (0–10 cm) in forest sites of the Asola-Bhatti Wildlife Sanctuary

Study sites	Physico-Chemical Characteristics Of Soil ± SE (n = 5)							
	Soil moisture (%)	Sand (%)	Clay (%)	Silt (%)	Texture Class	Bulk density ($Mg\ m^{-3}$)	Soil pH	Organic C (%)
UD	10.92 ± 1.16	46	20	34	Sandy Loam	1.54 ± 0.01	5.94 ± 0.06	0.98 ± 0.19
SRMP	15.42 ± 1.03	55	19	27	Sandy Loam	1.73 ± 0.07	8.08 ± 0.10	0.73 ± 0.12
SRMS	7.60 ± 0.21	63	16	20	Sandy Loam	1.66 ± 0.05	6.82 ± 0.09	0.56 ± 0.06
HD	4.36 ± 0.37	78	18	4	Sandy Loam	1.79 ± 0.13	8.29 ± 0.17	0.29 ± 0.03

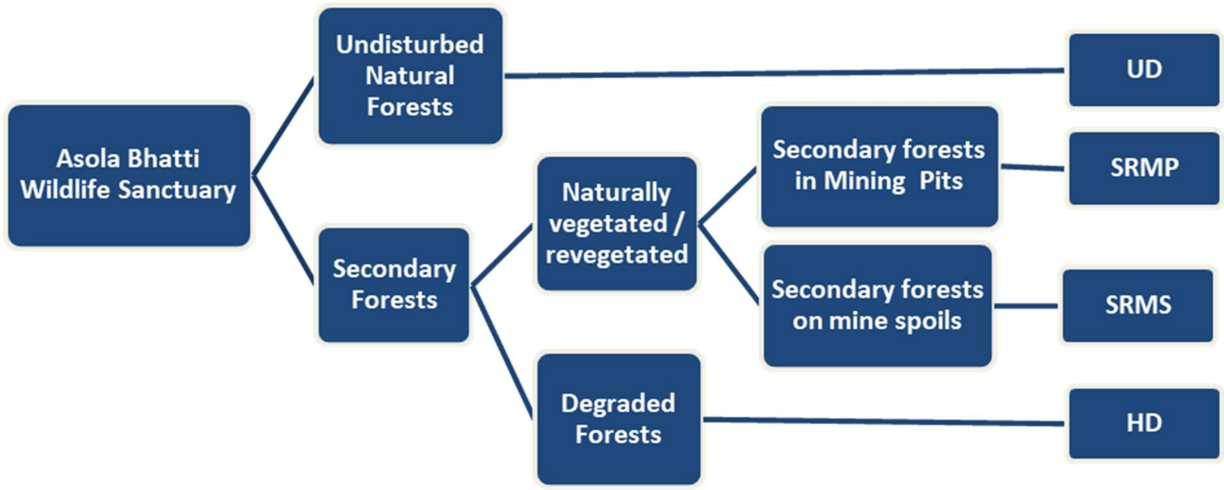

Fig. 3: Flow chart depicting the study site characterisation

density was recorded higher in secondary forests (highest in HD site) than in the natural undisturbed site, which show high soil compaction and low availability of organic carbon in mining affected sites. Numerous studies have demonstrated that excessive surface grading and high soil density often impairs survival and growth of trees planted on mines (Torbert and Burger, 1990; Andrews *et al*., 1998; Torbert and Burger, 2000; Jones *et al*., 2005). Moisture content, organic carbon, available N, P and K of the soil were greater in the natural forests as compared to secondary forests. Poor contents of moisture NO_3-N, PO_4-P, organic matter, high level of biologically unavailable form of iron and lack of soil cover suggest that the abandoned Bhatti mine was characterized with a wide range of abiotic stresses. Therefore, the physico-chemical characteristics of the habitat suggest that the area is non-amenable for natural colonization by plants (Fig.3).

Methods

Vegetation Index is commonly used for evaluating vegetation condition. To explore the effects land-use/land-cover change (LUCC) on vegetation coverage in the Asola-Bhatti Wildlife Sanctuary, a proxy for the vegetation health namely the Normalized Difference Vegetation Index (NDVI) was used. The NDVI is the most widely used tool to assess recovery processes, as it is sensitive to changes in the fractional vegetation cover until a full cover is reached. The NDVI has been shown to be correlated with the green biomass, leaf area index and other measures of "greenness". The high NDVI means better vegetation conditions. Where NDVI is less than or equal to zero (NDVI = 0), the land cover types are most likely bare ground without vegetation such as rocky outcrops and water bodies, so that they were excluded from the quantitative analysis.

NDVI was derived from the Landsat imageries using the ERDAS Imagine software (ERDAS Inc., Atlanta, GA, USA).

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

where NIR is reflectance in the near-infrared band and RED is reflectance in the visible red band. The 1992 Landsat TM, 1999 and 2006 Landsat ETM+ and 2013 Landsat OLI images were used to analyse vegetation conditions over the study period. The NDVI was calculated using Bands 3 and 4 of Landsat 5 (TM) and 7 (ETM+), and Bands 4 and 5 of Landsat 8 (OLI) as red and near-infrared bands, respectively. The resulting NDVI images were then compared and thresholds were used to categorize the vegetation change along different temporal scales.

For the analyses of soil properties, three soil samples were collected to a depth of 10 cm, from each subplot. These samples were analyzed for texture (Sheldrick and Wang, 1993), pH (Anderson and Ingram, 1993), organic Carbon (Walkley and Black, 1934), total N (Bremner and Mulvaney, 1982), and total P (Olsen and Sommers, 1982) content.

The vegetation analysis was done during two successive years 2013 and 2014 in the month of August to October, when the forest floor was fully covered by vegetation so that maximum plant diversity could be achieved. The size of the quadrat used in this study was decided based on the species area curve method following Misra (1968) and the running mean method (Kershaw, 1973). At each site 10 quadrats (10 m x 10 m) were laid for sampling the tree stratum, 3m x 3m quadrats (10 quadrats) were used to quantify shrubs and 1m x 1m quadrats (10 quadrats) for herbs and grasses. In each quadrat the individual trees were enumerated and for each tree diameter at breast height (DBH) from the ground was recorded. Collar diameter in case of herbs and grasses with the help of tree calliper and electronic digital calliper was recorded. In case of grasses and sedges, each erect shoot was considered to be a plant tiller and the enumeration was done by laying 1m x 1m quardrats at random, further subdivided into 10cm x 10cm segments. Four such segments selected at random were analysed from each quadrat by counting the tillers individually. The structure and composition of vegetation across vegetation types was compared in terms of frequency, density and basal area of major species. Importance Value Index (IVI = relative frequency + relative density + relative dominance) was derived from the primary data separately for each layer following Misra (1968). Diversity index was calculated following Shannon and Wiener (1963) as follows:

$$H' = \sum_{i=1}^{s} pi \ln pi$$

where pi is the proportion of individuals of i^{th} species and total number of individuals of all species.

The concentration of dominance was calculated following Simpson (1949) as follows:

$$Cd = \sum_{i=1}^{s} (pi)^2$$

where pi is the proportion of individuals of i^{th} species and total number of individuals of all species.

The species evenness or equitibility was calculated following Pielou (1975) as follows:

$$J' = \frac{H'}{Hmax}$$

where H' is the Shannon diversity index and H_{max} is the Shannon maximum diversity index, which was calculated as follows:

$$Hmax = \ln(S)$$

where S = the total number of species in the forest site.

Species richness index (d) indicating the mean number of species per sample (Margalef, 1958) was calculated as $d = S/\sqrt{N}$, where, S= number of species, N= number of individuals of all species. Sorensen's similarity index (Sorensen, 1948) was calculated as, [2C/(A + B)] × 100, where, A and B are the total species content (trees, shrubs or herbs) in stand A and B respectively, while C is the number of species common to both sites. Family relative diversity (%) was calculated as, (Number of species in a family/total number of species) × 100. A disturbance index was calculated as the ratio of tree density in secondary forests as compared to that of the undisturbed natural stand (UD), was expressed in percentage (Nath *et al.*, 2005). The SRMP site was 11% disturbed, and SRMS site was 25% and HD site was approximately 66% disturbed as compared to the UD site.

Importance value Index (IVI) calculated from primary data for each layer including trees, shrubs, climbers, herbs and grasses in all the treatments i.e. along all the study sites were classified using Principal Component Analysis (PCA) to analyse plant species and various associations between them. The PCA was performed in the R software environment (v.2.15.2; R Development Core Team, 2012) using Vegan package.

RESULTS

(a) Normalized Difference Vegetation Index (NDVI)

The analysis showed that, in the past 21 years, the ABWLS experienced an uptrend in vegetation regeneration as a whole; while certain forest areas which were in proximity of human settlements were in the process of degradation. The NDVI images obtained for the year 1992, 1999, 2006 and 2013 indicate a dynamic increase in vegetation greenness during the period (Fig. 4). In particular the areas in the southern part i. e. Bhatti region of ABWLS where mining dominated the land use, the lowest levels of NDVI exist and this stretch has consistently increased greenness values from 1992 through 2013. Areas along human settlements showed a lower value of NDVI depicting anthropogenic pressure, in these areas. The area of ABWLS registered NDVI value less than 0.075 but greater than zero which indicates that the sanctuary majorly has low and medium scrub forest in rocky outcrops.

(b) Floristic Composition and Abundance

A total of 102 species (17 trees, 15 shrubs, 10 climbers, 33 herbs and 27 grasses) belonging to 35 families were recorded in all the sites. Among families, Poaceae (26 species), Fabaceae (15 species), Acanthaceae and Asteraceae (5 species each) and Malvaceae and Tiliaceae (4 species each) were most species diverse. Capparidaceae, Convolvulaceae, Rhamnaceae and Euphorbiaceae were represented by 3 species each; Apocynaceae, Amaranthaceae, Bignoniaceae, Caesalpiniaceae, Moraceae and Zygophyllaceae by 2 species each; and remaining 19 families were monospecific. The number of families in the study sites for trees was 11, for shrubs was

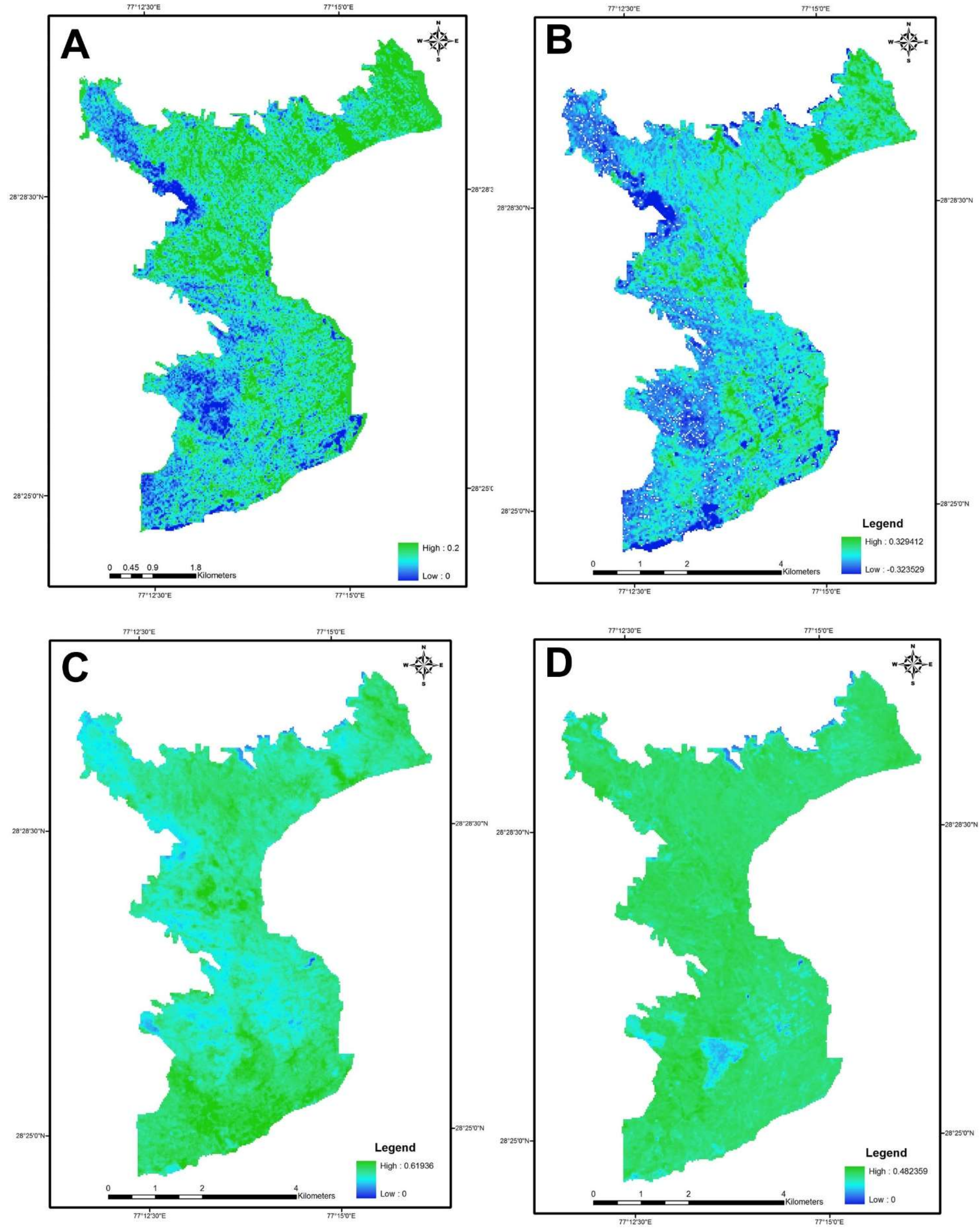

Fig. 4: Normalized Difference Vegetation Index (NDVI) during (**A**)1992, (**B**)1999, (**C**)2006 and (**D**) 2013 in ABWLS.

Table 3: Vegetation Composition in different forest types at Asolla-Bhatti Wildlife Sanctuary

Forest Site		Density (no. ha^{-1})	Basal Area ($m^2 ha^{-1}$)	Vegetation Composition
UD	Trees	850	11.99	Ten tree species present including *Diospyros montana* var. *Cordifolia* (IVI=65.7), *Balanitis aegyptiaca* (IVI=56.48), *Acacia senegal* (IVI=51.92), *Butea monosperma*, *Ehretia laevis* and 5 others; 13 shrub species (IVI ranging between 66.44 to 4.81); 8 climber species (Basal area=0.49 m^2 ha^{-1}); 18 herbaceous species (Total Density=76500 plants ha^{-1}); 9 grass species were present (all belonging to Poaceae family).
	Shrubs	12543	3.42	
	Climbers	49000	0.49	
	Herbs	76500	1.14	
	Grasses	137000	0.12	
SRMP	Trees	760	7.93	Seven tree species were recorded of which *Prosopis juliflora* was dominant (IVI=175.49); 10 shrub species including Capparis sepiaria (IVI=53.61), Carissa opaca (IVI=52.33); *Jasminum multiflorum*(IVI=123.16) was dominant amoung the total 5 climber species; 17 herb species (IVI ranging from 63.64 to 4.00) of which the most dominant was *Parthenium hysterophorus*; 12 grass species were present.
	Shrubs	6653	1.47	
	Climbers	13000	0.23	
	Herbs	124600	1.51	
	Grasses	220900	1.46	
SRMS	Trees	640	6.32	5 tree species were present including *Prosopis juliflora* (IVI = 214.19), *Flacourtia indica* (IVI=31.36), *Balanitis aegyptiaca* (IVI=27.93), *Holoptelea integrifolia* (IVI=14.45), Tecomella undulate (IVI=12.04); 4 shrub species (IVI ranging from 99.19 to 31.83); 2 climber species; *Carissa pumila* was the most dominant among 4 herb species, 5 grass species were present, all belonging to poaceae family.
	Shrubs	5555	0.72	
	Climbers	555	0.04	
	Herbs	53000	0.13	
	Grasses	201400	0.33	
HD	Trees	290	3.69	Apart from *P. juliflora* (IVI=239.07), *Anogeissus pendula* was present in a stunted form under extreme degradation (IVI contribution 15.3%) and rest by *Acacia senegal* (IVI contribution 5.01%). 4 shrub species were present, of which *Securinega leucopyrus* was the most dominant (IVI contribution 128.37) ; No climber species present; 12 herbaceous species were recorded (IVI ranging between 63.04 to 5.77) and 12 grass species were present.
	Shrubs	1110	0.069	
	Climbers	-	-	
	Herbs	140000	1.13	
	Grasses	153000	1.55	

14, for climbers was 7, for herbs was 16 and in case of grasses the no. of families was 2. For trees, the most diverse family in all four sites was Fabaceae contributing 40% in UD site, 42.6% in SRMP, 20% in SRMS and 66.7% in HD site. Among grasses the most diverse family in all four sites was Poaceae (UD, SRMP and SRMS site contribution was 100 %; whereas in HD the contribution was 91%). The mining pits were at difficult terrain far from human settlements and not in proximity of livestock, hence acted as a closed system. These mining pits of the sanctuary have been under isolation of more than 20 to 28 years and showed striking results as they regenerated a significant proportion of their phyto-diversity and now are the houses of plant diversity.

(c) Vegetation Composition

Overall, there were 17 tree species distributed across 11 families, out of which no single species was common to all the sites (Table 3). Nonetheless, the number of tree species was highest in UD site (10 species) in which *Acacia senegal, Balanitis aegyptiaca and Diospyros montana var. cordifolia* contributed 66% of the total tree density. Total density and total basal area of trees was highest in UD site followed by SRMP site, SRMS site and recorded lowest in HD site. The same trend was true for shrubs. However, the reverse trend was observed in case of herbs for which highest total density and total basal area was recorded in HD site, followed by SRMP, followed by UD site and was recorded lowest in SRMS. Similarly, for grasses highest total density and total basal area was recorded in SRMP site and was recorded lowest in UD site. *Prosopis juliflora* was absent in undisturbed site whereas was the dominant tree species in all other three secondary forests with an IVI contribution of 58.4%, 71.3% and 79.7%, respectively in SRMP, SRMS and HD. A total of 15 shrub species were recorded in the area representing 14 families, out of which *Securinga leucopyrus* was the only species common in all four sites. For climbers the species richness was recorded highest in UD site (8 species) whereas climbers were completely absent in HD site. A total of 33 herb species were recorded in the study area representing 16 families, out of which *Boerhavia diffusa* was the only species common in all four sites. The number of herbaceous species was lowest in SRMS site whereas highest in UD site. Grasses were few in protected as well as in undisturbed forests site however was highest in HD site. Increase in ground flora in disturbed site may partly be a response to a more open environment where tree cover is minimal and consequent reduced competition. Thus, species with shorter life history strategy have an advantage over those with longer life span because the former could be more successful under certain environmental condition (Nath *et al*., 2005). In all four forest sites, majority of the species were represented by few individuals and only a few species had relatively large population density. The PCA species plot (Fig. 5) showed that gradients reflect change in the major species between different sites (Species codes of all species mentioned in Appendix 1).

(d) Species Diversity

The species diversity, concentration of dominance, species richness and species evenness of different layer of forest sites are depicted in Table 4. The Shannon indices (H') for trees, shrubs, climbers and herbs was recorded highest on UD site whereas lowest H' index was observed

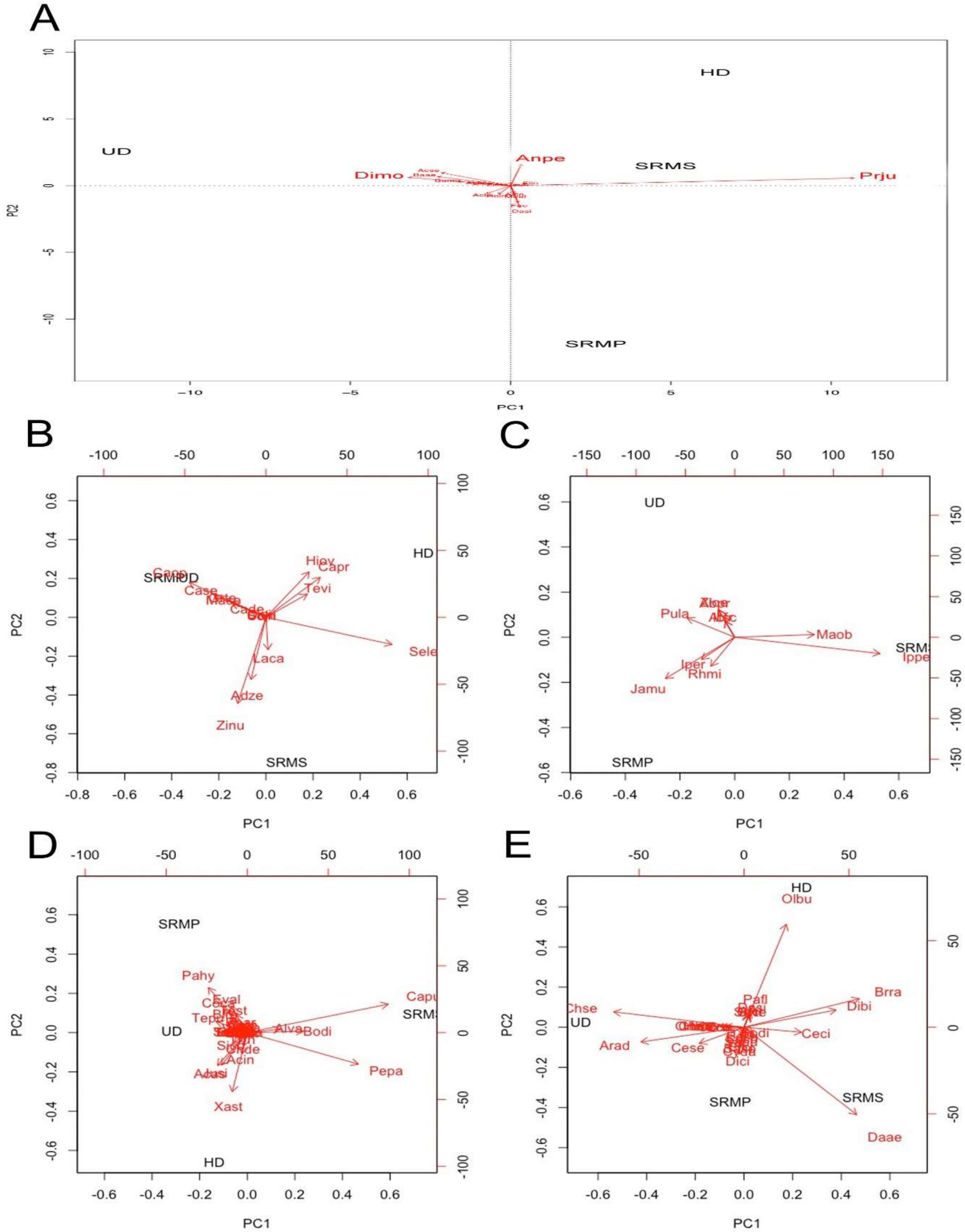

Fig 5: (A) Principal Component Analysis of Tree component, (the first two axis PC1 and PC2 explaining 95.63 % of the variance), indicating the movement of the three secondary forest sites towards invasion by *P. juliflora* and higher species diversity clustered at UD site. (Species Codes for all the species along all the layers are mentioned in the Appendix 1) **(B)** Principal Component Analysis of Shrub component, (the first two axis PC1 and PC2 explaining 88.45 % of the variance), indicating similar shrub composition in SRMP and UD site; invasive species (*L. Camara)* clusturring towards SRMS site. **(C)** Principal Component Analysis of Climber component, (the first two axis PC1 and PC2 explaining 100 % of the variance), indicating more diversity in UD site; disturbed site dominated by few species. **(D)** Principal Component Analysis of Herb component, (the first two axis PC1 and PC2 explaining 86.92 % of the variance), indicating species clustering at UD, SRMP and HD sites but very low in SRMS site **(E)** Principal Component Analysis of Grass component, (the first two axis PC1 and PC2 explaining 83.77 % of the variance), indicating very low diversity in SRMS site compared to other three sites.

Table 4: Phyto-sociological analysis and community indices of forest sites

	Study sites	No. of Families	Simpson Index	H'	Species Evenness	Margalef's Index
Trees	UD	7	0.14	2.10	0.91	1.33
	SRMP	4	0.38	1.39	0.63	0.90
	SRMS	5	0.53	0.97	0.54	0.62
	HD	2	0.66	0.62	0.56	0.35
Shrubs	UD	12	0.12	2.29	0.89	1.27
	SRMP	9	0.13	2.13	0.92	1.02
	SRMS	4	0.28	1.31	0.95	0.35
	HD	4	0.30	1.30	0.94	0.43
Climbers	UD	7	0.16	1.95	0.94	0.65
	SRMP	4	0.27	1.43	0.89	0.42
	SRMS	2	0.54	0.65	0.94	0.16
	HD	0	-	-	-	-
Herbs	UD	13	0.07	2.77	0.96	1.51
	SRMP	9	0.10	2.51	0.89	1.36
	SRMS	4	0.30	1.27	0.92	0.28
	HD	8	0.13	2.23	0.90	0.93
Grasses	UD	1	0.18	1.95	0.89	0.68
	SRMP	1	0.10	2.38	0.96	0.89
	SRMS	1	0.27	1.42	0.88	0.33
	HD	2	0.17	2.04	0.85	0.84

in case of trees and shrubs for HD site. However lowest H' in case of herbs and grasses (1.39 and 0.33) was recorded on SRMS site of ABWLS. Highest H' index for grasses was witnessed for SRMP. Similarly, species richness was recorded maximum for the tree, shrub, climber and herb components in UD site whereas lowest was observed for HD site however minimum in case of grasses was observed in SRMS site of ABWLS. Dominance index was the reverse of that for Diversity Index. Species Evenness for tree species was recorded highest in UD site but lowest for SRMP site, whereas for shrub layer, this tended to be lowest in the UD site. Margalef's index for trees, shrubs, climbers and herbs was recorded highest in case of UD site whereas for grasses maximum.

(e) Dominance Diversity Curves

Dominance distribution curves for the tree layer (based on Importance Value Index) to interpret the community organization in terms of resource share and niche space are shown in Fig. 6. In UD site, the dominance distribution curve was relatively longer than other three sites in which the curve was sharper and short indicating less equitable distribution of species. The importance value (IVI) distribution curve tree species indicates that more than one tree species shares the dominance in the community in UD Site however sporadic distribution of single mature tree species in other sites resulted in the gradual decline in the IVI curve. *Diospyros montana var. cordifolia, Balanitis aegyptiaca and Acacia senegal* contributed 59% to the total importance value of the tree community in UD site. In other three secondary forest sites one tree species dominates the community i.e. *Prosopis juliflora* (approximately 76%, 84% and 83% to the total importance value of the tree community in SFMP, SFMS and UD forest respectively).

Similarity coefficient among different sites suggest that the differences get magnified under contrasting regeneration and disturbance regimes (Table 5). The similarity indices determined for tree layer (23.5%), shrubs (69.57%), climbers (46.2%), herbs (45.7%) and grasses (28.57%) showed maximum similarity indices between the UD site and SRMP site. Least similarity of plant species was observed among UD site and HD site. Further, similarity coefficient showed more pronounced differences for the tree components compared to shrubs, suggesting that the tree components were more adversely affected by disturbance than the shrub, herb and grass strata.

Table 5: Similarity indices between tree, shrub and herb components of three of the four forest sites

Site		SRMP	SRMS	HD
UD	Trees	23.53	26.67	30.77
	Shrubs	69.57	47.06	35.29
	Climbers	46.15	20.00	0.00
	Herbs	45.71	9.09	40.00
	Grasses	28.57	14.29	19.05
SRMP	Trees	-	33.33	20.00
	Shrubs	-	28.57	42.86
	Climbers	-	28.57	0.00
	Herbs	-	19.05	48.28
	Grasses	-	23.53	16.67
SRMS	Trees	-	-	25.00
	Shrubs	-	-	25.00
	Climbers	-	-	0.00
	Herbs	-	-	25.00
	Grasses	-	-	47.06

DISCUSSION

Ecosystems are in a continuous state of change, either due to natural succession or degradation due to anthropogenic pressure (Roy *et al*. 2012). Meeting the livelihood needs is the basic objective to meet food, fodder and fuelwood of the local community which is for ensuring the success of any restoration programme. This study analyzes the spatial changes in phytosociology of various categories of natural forests and post mining regenerating forests in the mining affected areas.

The remote sensing techniques used in this study are useful tools, capable of aiding in the process of monitoring forest cover changes caused by mining activities and can be used as an indicative tool for the *prima facae* assessment of forest regeneration. NDVI has been frequently used in surface mining studies and has proven useful to map the areas affected by this activity (Prakash and Gupta, 1998; Erener, 2011; Fernández-Manso, 2012). The decadal NDVI images indicate a dynamic increase in vegetation greenness during the protection phase signifying increase in forest cover within sanctuary. The NDVI images at different time periods clearly show a very quick regeneration of

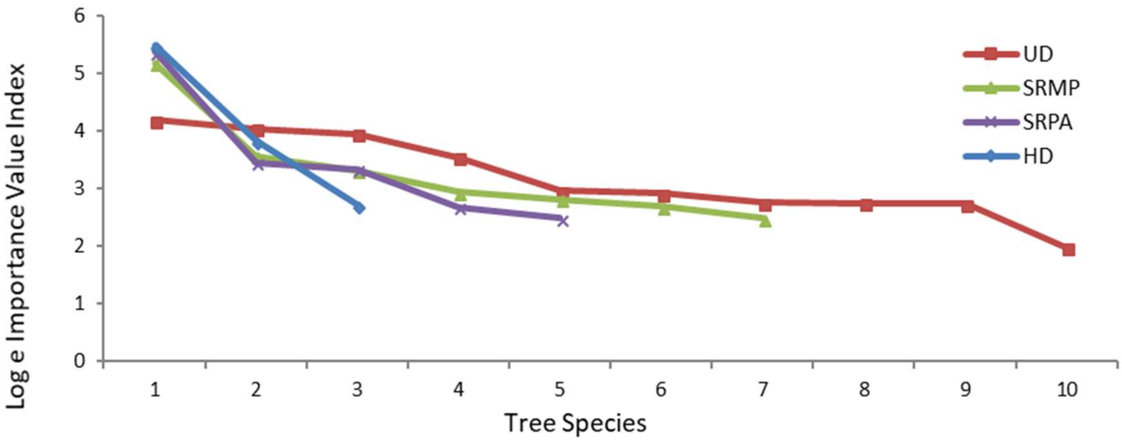

Fig. 6: Importance value distribution curve of tree species in all study sites of Asola-Bhatti Wildlife Sanctuary

secondary forests throughout the sanctuary.

The undisturbed natural forest (UD) with total 58 species of trees, shrubs, climbers, herbs and grasses represents the climax stage in the semi-arid environment of the Aravalli mountain ranges in Asola-Bhatti Wildlife Sanctuary. Certain species such as *A. nilotica, B. monosperma, D. montana* and *E. laevis* were found to be sensitive to human disturbance and these have been completely wiped out from the sanctuary, except from undisturbed forest. Thus, tree species exhibit low regeneration potential under the prevailing mining disturbed environmental conditions. It is interesting to note that *A. pendula* not only survived but exhibited medium density even in the degraded forest (HD). This indicated that *A. pendula* had high regeneration potential in the semi-arid as well as in the highly disturbed conditions.

The higher basal area of trees in the undisturbed forest correlated well with the higher biomass accumulation and carbon sequestration potentials of the climax vegetation of the region. About 34% and 47% reduction in the basal area in SRMP and SRMS sites respectively as compared to the UD site depicts the recent regeneration. However, 69.23% reduction in basal area in HD site as compared to UD site is attributed to high anthropogenic pressure, selective felling and the poor regeneration rate. In dry forest, basal area has been reported to be about 30 to 75% that of wet forest (Ogawa *et al.,* 1965; Misra, 1972; Garg and Vyas, 1975; Brunig, 1983).

The results of the present study indicate that this fragile forest ecosystem is under high anthropogenic pressure. The species richness, density and basal cover of most of the species were relatively higher in the undisturbed natural forest as compared to the secondary forest areas. It is observed thatselective removal of trees facilitated the growth of grass species that compete with the tree seedlings and saplings for nutrients and space. This may lead to poor tree regeneration of native species in the disturbed forest sites of highly disturbed forest.

The effect of regeneration and anthropogenic disturbance on the diversity of all species was very striking. Tree, shrubs and herbaceous species diversity in the UD site was highest, however in case of grasses highest diversity was recorded in SRMP site. The diversity index of tree species was very low in ABWLS study sites (1.30 – 2.07) as compared to 2.48 of tropical dry deciduous forests of Varanasi (Singh *et al*., 1992), which may be attributed to stressed environment due to mining, extremes of temperature and drought conditions. The species diversity index decreased, whereas the concentration of dominance increased with the increase in human disturbance. Similar observations have also been made by Rao *et al*. (1990) in a sub-tropical broad-leaved forest. A decrease in species diversity and increase in concentration of dominance with increase in biotic disturbance has been observed in a dry deciduous forest of Aravallies (Yadav and Gupta, 2006). Resource sharing and niche space occupation are frequently shown by dominance diversity curves (Whittaker 1975); in the present study wide and long dominance diversity curves signifies stability of community as seen in UD site, while regenerating and degraded forest were characterised by steeper curves due to their reduced dispersion values indicating occurrence of only a few dominant species.

Successful non-indigenous species are capable of displacing native species and altering community structure (Elton 1958; Coblentz 1990; Mukherjee *et al.,* 2017). In this study, we observed the spread of invasive *P. juliflora* throughout the sanctuary. *P. juliflora* was absent in undisturbed natural forest but was the most dominant tree species in all other three types of secondary forests with a density contribution of 76.32%, 84.38% and 82.76%, respectively in SRMP, SRMS and HD sites. Large thickets of *P. juliflora* form the main vegetation cover in the ABWLS. Vegetation under it showed a significantly lower ground herbaceous cover. The reduced ground cover under *P. juliflora* is due to shading as well as some allelopathic or competitive interactions (Goel *et al.,* 1989; Noor *et al*.,1995; Nakano *et al.* 2003; Kaur *et al.*

2012; Mukherjee *et al.*, 2017).

The invasive *P. juliflora* which has replaced most of native trees and shrubs is emerging as a major threat to ecosystem. Strong negative impacts of *P. juliflora* on the richness, evenness and densities of other plant species in secondary forests are clearly evident. The controlled harvesting of *P. juliflora* as fuelwood could enhance the growth of grasses. The various management strategies involve reduction of anthropogenic pressure, controlled livestock dependency, removal of seedlings of *P. juliflora* at the early stage. *Butea monosperma, Wrightia tinctoria* and *A. pendula* are restricted to rocky terrain in the study area and are therefore habitat specialist on a relative scale. *B. monosperma* and *A. pendula* had thin population due to their exploitation for fodder and fuel, and therefore need to be protected. *Securinega leucopyrus* and *Ziziphus nummularia* were common to all the sites which is a reflection of their generalist habits.

Twenty four percent similarities between the undisturbed forest and the previously disturbed (now protected) regenerating forest suggests that the original composition of the community could not be restored even after 25 years of protection. It may be suggested that once the damage is caused to the community due to human disturbance, the original floristic composition may not be restored which may be because of the fixity of the plant species, poor dispersal mechanism of their propagules and the severe environmental conditions prevailing in the Aravalli mountain ranges. In such fragile forest ecosystems, there seems to be no alternative to *in-situ* conservation.

CONCLUSION

The effects of changes in community composition or biodiversity loss on the functioning of ecosystems have been the focus of much ecological research. Restoration of degraded sites should take into consideration the ecological processes centred on successional concepts. The conservation of the forest fragment in the proximities of the area degraded by mining was essential for the natural regeneration of shrub and tree species, acting as a seed source and refuge for disperser animals. Natural succession in the post-mining area should be aided by human intervention in order to accelerate the reclamation of the area. Research on the ability of the forest to colonize severely disturbed areas and whether changes in mining practices could accelerate forest regeneration should be encouraged. The introduction of alien tree species in the forests should be seriously discouraged, and only indigenous/native tree species should be planted. The replacement of pioneer species by native forest trees will take much longer and it may be centuries before the vegetation of mining pits resembles that of natural forests. Reforestation of abandoned and degraded tropical mining lands has great potential to increase rates of Carbon sequestration from the atmosphere and enhance biodiversity. The magnitude of this potential has not been widely quantified, but is important for the development of management strategies and national and international policies. The good conservation efforts in ABWLS have resulted in considerable natural regeneration of secondary forests in the degraded habitats including pits and mine spoils but warrants more protection from human intervention and also eco-development to meet the livelihood requirements of the local inhabitants in the peripheral areas of the ABWLS in order to reduce the anthropogenic pressure on the natural resources of the sanctuary.

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Appendix 1. Species Codes along with Species recorded along all the layers in ABWLS.

Trees

Acle = *Acacia leucophloea; Acni = Acacia nilotica; Acse = Acacia senegal; Anpe = Anogeissus pendula; Azin = Azadirachta indica; Baae = Balanitis aegyptiaca; Bumo = Butea monosperma ; Dasi = Dalbergia sissoo; Dimo = Diospyros montana var. cordifolia ; Ehla = Ehretia laevis ; Fire = Ficus religiosa; Flin = Flacourtia indica; Hoin = Holoptelea integrifolia; Moal = Morus alba; Prju = Prosopis juliflora; Teun = Tecomella undulate; Zima = Ziziphus mauritiana.*

Shrubs

Adze = Adhotoda zeylanica; Capr = Callotropis procera; Cade = Capparis deciduas; Case = Capparis sepiaria; Cap = Carissa opaca; Cohi = Cocculus hirsutus; Dici = Dichrostachys cinerea; Grte = Grewia tenax; Hiov = Hibiscus ovalifolius; Laca = Lantana camara; Mase = Maytenus senegalensis; Sele = Securinega leucopyrus; Soin = Solanum incanum; Tevi = Tephrosia villosa; Zinu = Ziziphus nummularia.

Climbers

Abpr = Abrus precatorius; Atsc = Atylosia scarabaeoides; Icfr = Ichnocarpus frutescens; Iper = Ipomoea eriocarpa; Ippe = Ipomoea pestigridis; Jamu = Jasminum multiflorum; Maob = Maerua oblongifolia; Pula = Pupalia lappacea; Rhmi = Rhynchosia minima; Zioe = Ziziphus oenoplia

Herbs

Acin = Acalypha indica; Acas = Achyranthes aspera; Agco = Ageratum conyzoides; Alva = Alysicarpus vaginalis; Blma = Blepharis maderaspatensis; Blre = Blepharis repens; Bodi = Boerhavia diffusa; Boar = Borreria articularia; Capu = Cassia pumila; Cato = Cassia tora; Chal = Chenopodium album; Coca = Corchorus capsularis; Chde = Chorchorus depressus; Euhi = Euphorbia hirta ; Eval = Evolvulus alsionoides; Inen = Indigofera enneaphylla; Inli = Indigofera linifolia; Jusi = Justicia simplex; Maco = Malvastrum coromandelianum; Ocam = Ocimum americanum; Oxco = Oxalis corniculata; Pahy = Parthenium hysterophorus; Pepa = Peristrophe paniculata; Seor = Sesamum orientale; Sico = Sida cordata; Sirh = Sida rhombifolia; Tepu = Tephrosia purpurea; Test = Tephrosia strigosa; Trte = Tribulus terrestris ; Trpr = Tridex procombens; Trrh = Triumfetta rhomboidea; Veci = Vernonia cinerea; Xast = Xanthium strumarium.

Grasses

Alci = Alloteropsis cimicina; Arad = Aristida adcendens; Brra = Brachiaria ramose; Ceci = Cenchrus ciliaris; Cese = Cenchrus setigerus; Chdo = Chloris dolichostachya; Chse = Chrysopogon serrulatus ; Cyda = Cynodon dactylon; Cytr = Cyperus triceps; Daae = Dactyloctenium aegyptium; Dasi = Dactyloctenium sindicum; Dibi = Digitaria bicornis ; Dici = Digitaria ciliaris; Ecco = Echinochloa colona; Erci = Eragrostis ciliaris; Erte = Eragrostis tenella; Heco = Heteropogon contortus; Occo = Ochthochloa compressa; Olbu = Olismenus burmanii; Orth = Oropetium thomaeum; Pafl = Paspalidium flavidum; Sasp = Saccharum spontaneum; Sapu = Sateria pumila; Seve = Setaria verticillata; Spco = Sporobolus coromandelianus; Spdi = Sporobolus diandur; Trbi = Tragus biflorus.