Ecologia

ISSN 1996-4021

Academic
Journals Inc.

www.academicjournals.com

Ecologia 1 (1): 44-55, 2011
ISSN 1996-4021 / DOI: 10.3923/ecologia.2011.44.55

Floristic Diversity in Ecologically Restored Lime Stone Mines and Natural Forests of Mussoorie and Doon Valley, India

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ABSTRACT

A comparative study of two restored limestone mine sites with adjoining natural forests has been undertaken to evaluate the impact of restorative interventions on floristic structure and composition. Sahastradhara and Chunakhala located in Doon valley and Mussoorie hills, Uttarakhand, India. The ecological restoration of both mines was done in 1988-89. Species diversity of Chunakhala and Sahastradhara restored sites was 1.74, 1.85, 0.57 and 1.44, 2.0, 1.9 for herbs, shrubs, trees respectively and for their adjoining natural sites was 1.99, 1.91, 1.2 and 2.2, 1.59, 2.55, respectively. Phytodiversity assessments in all the sites lead to the conclusion that Sahastradhara restored site represents higher diversity of shrubs and trees than Chunakhala restored site as well as its adjoining natural forests. This paper describes the floristic composition and species diversity of these two mined areas after 21-22 years old restoration and also states a comparison with their nearby natural forests.

Keywords: Ecological restoration, degraded land, succession, importance value index, species diversity index, similarity index

INTRODUCTION

Mining and mineral processing adversely affects the ecology of the area by disturbing the land mass, the water systems and floral-faunal populations and in turn the quality of human life. Garhwal Himalayas of Uttarakhand covering an area of 30, 000 km^2 abound in forest, meadows, marshes and swamps with their characteristic plant composition. Doon valley and Mussoorie hills (Garhwal Himalayas of Uttarakhand, India) till early eighties faced a serious threat due to heavy limestone quarrying with 105 working mines in this region. After the cessation of mining activity restoration of these sites was undertaken by different agencies. The ecological restoration interventions were initiated in these areas during 1988-1989. Ecology of this region was adversely affected by large scale limestone quarrying. Although colonization of primary successional species initiates as a natural process on such disturbed sites, but it is a very slow process. After mineral extraction the derelict mined site faces low moisture retention and poor in nutrients besides other physico-chemical and physico-mechanical adverse conditions viz., high stone content, lack of moisture, higher compaction, shortage of soil forming materials and organic matter (Coppin and Bradshaw, 1982; Maiti and Singh, 2001). According to the Goma-Tchimbakala and Makosso (2008), on the re-vegetated degraded lands the amount of organic matter under plantations is found lower than in the natural forest due to the lack of litter, losses of organic matter by water erosion and high mineralization.

Ecorestoration put into practice has been proved as an effective tool to revegetate these disturbed fragmented forest sites. SER (2004) defined ecological restoration as an "Intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability". A successful restoration program attempts to accelerate the natural recovery process artificially in order to achieve the goal in a short time. The reclamation of derelict and degraded land involves in overcoming many problems (socio-economic, biological and technical) to restore a functional and self-sustaining soil-plant ecosystem (Anwer *et al.*, 2001). In the case of plantations established primarily for rehabilitation of severely disturbed sites, additional knowledge of watershed stabilization, native forest restoration and natural successional processes must be applied to establish structurally diverse and functionally stable forest ecosystems (Rouhi-Moghaddam *et al.*, 2007). Maiti and Singh (2007) mentioned some important issues for research and development in the field of ecorestoration as:

- Categorization of dumps based on reclamation potential and regeneration of ecosystem
- Drainage, sedimentation and erosion control
- Plantation of leguminous forbs and grasses as pioneer colony in dumps reclamation
- Ecorestoration technique of the forest area for Conservation of biodiversity and matching with surrounding landscape
- Soil ameliorants via Identification of suitable mulch and mulching technique
- Hydro-seeding (Coppin and Bradshaw, 1982) which involves spreading a layer of slurry containing seed mixtures, soil and other suitable germination media

Eco-rehabilitation results in the accelerated natural succession processes and increasing biological productivity reduce rates of soil erosion, increase soil fertility and increase biotic control over biogeochemical fluxes for the recovery of ecosystem (Parrotta, 1992). The selection of the right species played a very important role in determining the successful rehabilitate of the degraded forest land (Hassan *et al.*, 2007). Immigration of the taxa is also recognized as an important limiting factor in the progress of eco-restoration process (Miles and Walton, 1993) dispersion and germination of a suitable native species with heavy seeds is difficult at a bare land if it is not in very vicinity (Bradshaw, 1997). Artificial seeding of grasses and legumes or both has been a commonly used method to stabilize unconsolidated mine tailings and to encourage natural invasion of tree and shrub seedlings. This ultimately improves site fertility and moisture retention capacity (Vogel, 1973). Once the abandoned mine lands have vegetation growing on the surface, the regeneration of these areas for productive use has begun which ultimately improves site fertility and moisture retention capacity and accelerates the further spreading of green cover while improving the aesthetics of the area (Singh *et al.*, 2002).

Present study has been undertaken to evaluate the ecological status of two ecologically restored mining areas and compared with their adjoining natural forest (undisturbed by mining). This study has a great importance to be very useful as a chronosequence for further succession studies of the same areas.

MATERIALS AND METHODS

Two restored limestone mines in Doon valley (Sahastradhara) and Mussoorie hills (Chunakhala) were selected and observed phyto-sociologically in the March-April, 2007. Chunakhala limestone mine was situated on Dehradun-Mussoorie highway at a distance of 25 km

from Dehradun. The elevation of the study site varied between 1300-1500 m above the mean sea level. Geographically the site is situated between the longitude 30° 27'N and 78° 15'E. Sahastradhara limestone mine is located about 18 km from Dehradun town on the bank of Baldi River at an altitude of about 800 m on the same aspect of Mussoorie hills. The site is situated between 30° 23'N and 78° 8' E. The natural forests of Chunakhala falls in the subtropical forest zone which are monsoon forests, that are characterized by being leafless during latter part of winter and hot dry spring while the natural forest of Sahastradhara site has tropical mixed deciduous scrubby vegetation.

Phytosociological studies were carried out in the field as per the procedure followed by Misra (1968). Five nested quadrats were laid at each site for assessment of floristic composition of trees (10×10 m), shrubs (5×5 m) and herbs (1×1 m). The data collected was subjected to following ecological analysis:

Importance Value Index (IVI): Importance Value Index has been estimated by the formula using described by Phillips (1959).

Diversity index: Shannon and Wiener diversity index was calculated by the formula described by Shannon and Weaver (1963).

Similarity index: Similarity index of the species between two stands was calculated with the help of Sorenson (1948).

RESULTS

Floristic attributes of vegetation i.e. herbs, shrubs and trees of two restored sites and their adjoining natural forests are presented in Table 1 and 2. The number of herbs in Chunakhala restored site was 13 while in adjoining natural forests it was only 9 (Table 1). The main dominating herbaceous species in terms of Importance Value Index (IVI) with their corresponding density (individual ha^{-1}) and total basal cover (m^2 ha^{-1}) of Chunakhala restored site was *Erigeron mucronatus* (96.29, 152000 ind. ha^{-1}, 2.16 m^2 ha^{-1}) *Micromeria biflora* (38.16, 46000 ind. ha^{-1}, 0.62 m^2 ha^{-1}) and *Lepidagathis cuspidata* (seedlings) (35.03, 22000 ind. ha^{-1}, 1.14 m^2 ha^{-1}) while minimum IVI was represented by *Galium aparine* (4.44, 2000 ind. ha^{-1}, 0.02 m $^2ha^{-}$)^{1}and *Geranium nepalense* (5.62, 4000 ind. ha^{-1}, 0.06 m^2 ha^{-1}). In adjoining natural forests maximum IVI was *Geranium nepalense* (82.29, 14000 ind. ha^{-1}, 0.42 m^2 ha^{-1}) *Oplismenus compositus* (51.77, 32000 ind. ha^{-1}, 0.03 m^2 ha^{-1}) and *Erigeron mucronatus* (38.33, 28000 ind. ha^{-1}, 0.04 m^2 ha^{-1}) and minimum IVI was of *Oxalis corniculata* (8.18, 2000 ind. ha^{-1}, 0.01 m^2 ha^{-1}), *Reinwardtia indica* (12.7, 6000 ind. ha^{-1}, 0.02 m^2 ha^{-1}). In Chunakhala restored site diversity index (1.74) was less in comparison to adjoining natural forests (1.99). Species similarity of herbs in Chunakhala restored site and adjoining natural forests was 18.18 % as only two species of herbs were common at both sites (Table 3).

The number of shrubs of Chunakhala restored site was 12 while in adjoining natural forests only 9 species of shrubs were recorded. The main dominating shrub species in terms of Importance Value Index (IVI) with their corresponding density (individual ha^{-1}) and total basal cover (m^2 ha^{-1}) at Chunakhala restored site was *Rhus cotinus* (IVI 76.25, 3600 ind. ha^{-1}, 12.43 m^2 ha^{-1}), *Agave sisalana* (IVI 58.08, 480 ind. ha^{-1}, 19.22 m^2 ha^{-1}) and *Lepidagathis cuspidate* (IVI 54.15, 2640 ind. ha^{-1}, 6.48 m^2 ha^{-1}) while minimum IVI was for *rubus biflorus* (IVI4.74, 80 ind. ha^{-1},

Table 1: Phytosociological analysis of Chunakhala restored site and natural forest

	Frequency (%)		Density (Individual ha^{-1})		TBC (m^2 ha^{-1})		A/F Ratio		IVI		H'	
Species	CKR	CKN	CKR	CKN	CKR	CKN	CKR	CKN	CKR	CKN	CKR	CKN
Herbs												
Adiantum sp.	-	60		12000	-	0.05	-	0.03	-	32.67	-	0.22
Artemisia nilagirica	60	40	14000	12000	0.75	0.04	0.04	0.08	26.51	26.61	0.14	0.22
Berberis lycium (SDL)	20	-	2000	-	0.06	-	0.05	-	5.05	-	0.03	-
Boenninghausenia albiflora	40	20	10000	8000	0.30	0.01	0.06	0.20	14.70	13.14	0.11	0.17
Chrysopogon fulvus	40	-	6000	-	0.05	-	0.04	-	9.55	-	0.08	-
Clematis napaulensis	-	40	-	14000	-	0.09	-	0.06	-	34.23	-	0.24
Erianthus rufipilus	60	-	22000	-	0.51	-	0.06	-	25.28	-	0.19	-
Erigeron mucronatus	80	40	152000	28000	2.16	0.04	0.21	0.18	96.29	38.33	0.35	0.33
Eriophorum comosum	60	-	24000	-	0.48	-	0.07	-	25.43	-	0.20	-
Galium aparine	20	-	2000	-	0.02	-	0.05	-	4.44	-	0.03	-
Geranium nepalense	20	40	4000	14000	0.06	0.43	0.10	0.09	5.62	82.29	0.06	0.24
Hypericum oblongifolium (SDL)	20	-	4000	-	0.23	-	0.10	-	8.23	-	0.06	-
Lepidagathis cuspidata (SDL))	60	-	22000	-	1.14	-	0.05	-	35.03	-	0.19	-
Lespedeza juncea (SDL)	20	-	2000	-	0.10	-	0.05	-	5.72	-	0.03	-
Micromeria biflora	80	-	46000	-	0.62	-	0.07	-	38.16	-	0.28	-
Oplismenus compositus	-	80	-	32000	-	0.03	-	0.05	-	51.77	-	0.35
Oxalis corniculata	-	20	-	2000	-	0.01	-	0.05	-	8.18	-	0.07
Reinwardtia indica	-	20	-	6000	-	0.02	-	0.15	-	12.77	-	0.14
Total	580	360	310000	128000	6.47	0.72	0.94	0.88	300.00	300.00	1.74	1.99
Shrubs												
Agave sisalana	60	-	480	-	19.22	-	0.03	-	58.08	-	0.14	-
Berberis lycium	40	60	320	640	0.85	0.23	0.05	0.04	12.43	39.61	0.11	0.25
Callicarpa macrophylla	-	20	-	80	-	0.04	-	0.05	-	8.62	-	0.06
Colebrookea oppositifolia	20	40	80	160	0.26	0.11	0.05	0.03	5.11	19.10	0.04	0.10
Coriaria nepalensis	-	40	-	400	-	0.11	-	0.06	-	23.51	-	0.19
Debregeasia salicifolia	-	60	-	640	-	0.24	-	0.04	-	40.59	-	0.25
Dodonaea viscosa	30	-	320	-	1.53	-	0.07	-	12.03	-	0.11	-
Eupatorium adenophorum	60	20	1680	1760	1.62	0.22	0.12	1.10	30.68	50.48	0.29	0.37
Hypericum oblongifolium	40	-	320	-	0.94	-	0.05	-	12.63	-	0.11	-
Lepidagathis cuspidata	80	80	2640	880	6.48	0.38	0.10	0.03	54.15	58.01	0.35	0.30
Lespedeza *juncea*	20	80	240	640	0.34	0.30	0.15	0.03	6.78	48.74	0.09	0.25
Rhus cotinus	80	-	3600	-	12.43	-	0.14	-	76.25	-	0.37	-
Rubus biflorus	20	20	80	240	0.10	0.04	0.05	0.15	4.74	11.34	0.04	0.13
Rubus ellipticus	20	-	80	-	0.43	-	0.05	-	5.48	-	0.04	-
Rumex hastatus	60	-	800	-	1.28	-	0.06	-	21.65	-	0.20	-
Total	530	420	10640	5440	45.49	1.66	0.92	1.53	300.00	300.00	1.85	1.91
Trees												
Bauhinia retusa	20	100	20	180	8.83	7.22	0.05	0.02	54.42	150.04	0.12	0.36
Boehmeria rugulosa	-	20	-	20	-	0.43	-	0.05	-	17.62	-	0.15
Cupressus torulosa	80		440	-	12.34	-	0.07	-	189.52	-	0.17	-
Debregeasia salicifolia	40	20	80	100	3.07	3.34	0.05	0.25	56.06	61.65	0.28	0.35
Mallotus philippensis	-	80	-	100	-	1.13	-	0.02	-	70.70	-	0.35
Total	140	220	540	400	24.24	12.11	0.17	0.33	300.00	300.00	0.57	1.20

CKR = Chunakhala restored site, CKN = Chunakhala natural forest site, SDR = Sahastradhara restored site, SDN = Sahastradhara natural forest site, IVI = Important Value Index, H' = Diversity Index (Shannon and Wiener, 1963) SDL = Seedling, SPL = Sapling

Table 2: Phyto-sociological analysis of Sahastradhara restored site and natural forest

	Frequency (%)		Density (Individual ha^{-1})		TBC (m^2 ha^{-1})		A/F Ratio		IVI		H'	
Species	SDR	SDR	SDR	SDR	SDR	SDR	SDR	SDR	SDR	SDR	SDR	SDR
Herbs												
Adhatoda zeylanica (SDL)	-	60	-	16000	-	0.27	-	0.04	-	43.97	-	0.30
Artemisia nilagirica	-	20	-	8000	-	0.46	-	0.10	-	36.18	-	0.21
Buddleja asiatica (SDL)	-	20	-	2000	-	0.02	-	0.05	-	7.51	-	0.08
Chrysopogon fulvus	20	-	12000	-	0.36	-	0.30	-	41.20	-	0.33	-
Erianthus rufipilus	100	-	26000	-	1.42	-	0.03	-	133.17	-	0.36	-
Erigeron montanus	20	-	2000	-	0.11	-	0.05	-	14.91	-	0.12	-
Eriophorum comosum	60	20	6000	2000	0.41	0.06	0.02	0.05	47.60	9.73	0.24	0.08
Eulaliopsis binata	20	-	2000	-	0.07	-	0.05	-	13.77	-	0.12	-
Lantana camara (SDL)	-	40	-	10000	-	0.14	-	0.06	-	26.63	-	0.24
Lepidagathis cuspidata (SDL)	-	20	-	6000	-	0.41	-	0.15	-	31.71	-	0.18
Micromeria biflora	40	-	8000	-	0.58	-	0.05	-	49.35	-	0.28	-
Murraya koenighii (SDL)	-	100	-	16800	-	0.25	-	0.03	-	52.77	-	0.31
Oplismenus compositus	-	40	-	14000	-	0.08	-	0.09	-	27.80	-	0.29
Pogostemon benghalense (SDL)	-	20	-	2000	-	0.04	-	0.05	-	8.63	-	0.08
Sida cordifolia	-	40	-	8000	-	0.02	-	0.05	-	18.76	-	0.21
Smilax zeylanica	-	80	-	8000	-	0.20	-	0.01	-	36.31	-	0.21
Total	260	460	56000	92800	2.94	1.99	0.49	0.69	300.00	300.00	1.44	2.20
Shrubs												
Adhatoda zeylanica	40	60	400	2480	0.15	0.59	0.06	0.17	11.62	43.14	0.11	0.32
Agave sisalana	60	-	4320	-	13.69	-	0.30	-	124.32	-	0.37	-
Boehmeria platyphylla	20	-	80	-	0.01	-	0.05	-	4.53	-	0.03	-
Boehmeria rugulosa (SPL)	20	-	240	-	0.11	-	0.15	-	6.33	-	0.07	-
Callicarpa macrophylla	20	-	80	-	0.01	-	0.05	-	4.54	-	0.03	-
Cassia fistula (SPL)	-	60	-	320	-	0.19	-	0.02	-	18.34	-	0.09
Dodonaea viscosa	40	-	1040	-	0.35	-	0.16	-	17.70	-	0.20	-
Eupatorium adenophorum	80	20	2560	160	0.60	0.06	0.10	0.10	38.51	6.41	0.32	0.05
Ficus palmata	20	-	80	-	0.01	-	0.05		4.51	-	0.03	-
Hypericum oblongifolium	-	20	-	80	-	0.01	-	0.05	-	4.82	-	0.03
Lantana camara	60	100	1920	4080	0.97	1.89	0.13	0.10	31.88	89.31	0.28	0.36
Lepidagathis cuspidata	-	20	-	240	-	0.07	-	0.15	-	7.26	-	0.07
Mimosa himalayana	-	40	-	240	-	0.11	-	0.04	-	12.00	-	0.07
Murraya koenigii	40	100	240	4560	0.18	1.94	0.10	0.11	13.65	94.03	0.15	0.37
Pogostemon benghalense	-	20	-	80	-	0.04	-	0.05	-	5.34	-	0.03
Rubus biflora	20	20	160	160	0.03	0.04	0.10	0.01	5.27	6.08	0.05	0.05
Vallaris solanacea	-	20	-	240	-	0.03	-	0.15	-	6.44	-	0.07
Vitex negundo	60	-	800	-	0.84	-	0.06	-	22.58	-	0.17	-
Woodfordia fruticosa	20	20	80	160	0.03	0.08	0.05	0.10	4.61	6.83	0.03	0.05
Total	520	500	13040	12800	17.19	5.04	1.76	1.06	300	300.00	2.00	1.59
Tress												
Acacia catechu	80	40	200	40	1.50	1.29	0.03	0.03	71.56	14.27	0.37	0.14
Bauhinia retusa	-	40	-	60	-	4.74	-	0.04	-	23.25	-	0.19
Bauhinia variegata	-	40	-	100	--	12.89	-	0.06	-	43.58	-	0.25
Boehmeria rugulosa	20	-	20	-	0.07	-	0.05	-	10.15	-	0.11	-
Bombax ceiba	-	20	-	40	-	0.28	-	0.10	-	8.77	-	0.14
Cassia fistula	-	20	-	20	-	0.98	-	0.05	-	7.79	-	0.09

Table 2: Continued

Species	Frequency (%)		Density (Individual ha^{-1})		TBC (m^2 ha^{-1})		A/F Ratio		IVI		H'	
	CKR	CKN	CKR	CKN	CKR	CKN	CKR	CKN	CKR	CKN	CKR	CKN
Cocculus laurifolius	20	20	20	20	0.19	0.12	0.05	0.05	11.25	6.12	0.11	0.09
Cordia dichotoma	-	20	-	20	-	0.32	-	0.05	-	6.52	-	0.09
Dalbergia sissoo	40	20	40	20	0.87	2.08	0.05	0.05	27.30	9.90	0.18	0.09
Ficus hispida	40	-	80	-	1.84	-	0.02	-	43.00	-	0.26	-
Grevillea robusta	20	-	100	-	3.46	-	0.25	-	55.48	-	0.29	-
Jacaranda mimosaefolia	60	60	100	60	1.14	3.59	0.03	0.02	45.76	24.60	0.29	0.19
Leucenia leucocephala	-	40	-	60	-	3.71	-	0.04	-	21.27	-	0.19
Mallotus philippensis	-	40	-	160	-	14.98	-	0.10	-	54.59	-	0.31
Melia Azedarach	-	20	-	20	-	0.33	-	0.05	-	6.53	-	0.09
Pongamia pinnata	-	60	-	60	-	2.49	-	0.02	-	22.49	-	0.19
Syzygium cumini	20	60	20	60	0.32	0.86	0.05	0.03	12.50	19.35	0.11	0.19
Toona ciliata	20	40	40	100	1.09	2.94	0.10	0.06	23.11	24.42	0.18	0.25
Trema politoria	-	20	-	20	-	0.34	-	0.05	-	6.55	-	0.09
Total	320	560	620	860	10.47	51.95	0.63	0.78	300.00	300.00	1.90	2.55

CKR = Chunakhala restored site, CKN = Chunakhala natural forest site SDR = Sahastradhara restored site, SDN = Sahastradhara natural forest site, IVI = Important Value Index, H' = Diversity Index (Shannon and Wiener, 1963) SDL = Seedling, SPL = Sapling

Table 3: Species Similarity Index of mining and natural sites

Plant forms	Similarity index	
	Chunakhala restored and natural site	Sahastradhara restored and natural site
Herbs	18.18	11.76
Shrubs	57.15	50.00
Trees	57.15	48.00

0.10 m^2 ha^{-1}), *Rubus ellipticus* (5.21, 80 ind. ha^{-1}, 0.43 m^2 ha^{-1}) *Lespedeza juncea* (6.78, 240 ind. ha^{-1}, 0.34 m^2 ha^{-1}). In adjoining natural forests maximum IVI for shrubs were of *Lepidagathis cuspidata* (58.01, 880 ind. ha^{-1}, 0.38 m^2 ha^{-1}), *Eupatorium adenophorum* (50.48, 1760 ind. ha^{-1}, 0.22m^2 ha^{-1}), *Lespedeza juncea* (48.74, 640 ind. ha^{-1}, 0.30 m^2 ha^{-1}), *Debregeasia salicifolia* (40.59, 640 ind. ha^{-1}, 0.24 m^2 ha^{-1}) and minimum IVI were of *Callicarpa macrophylla* (8.62, 80 ind. ha^{-1}, 0.04 m^2 ha^{-1}) and *Rubus biflora* (11.34, 240 ind. ha^{-1}, 0.04 m^2 ha^{-1}). In Chunakhala restored site diversity index of shrub (1.85) was less in comparison to the adjoining natural forests (1.91). Species similarity of shrub in Chunakhala restored site and adjoining natural forests was 57.15% (Table 3). Six species of shrubs were common in both sites and Chunakhala restored site was more diverse in case of shrub diversity.

The number of tree species at Chunakhala restored site was 3 while 4 species were found at adjoining natural forests. The main dominating tree species in terms of Importance Value Index (IVI) with their corresponding density (individual ha^{-1}) and total basal cover (m^2 ha^{-1}) at Chunakhala restored site was *Cupressus torulosa* (189.52, 440 ind. ha^{-1}, 12.33 m^2 ha^{-1}), while *Debregeasia salicifolia* (56.06, 80 ind. ha^{-1}, 3.07 m^2 ha^{-1}) and *Bauhinia retusa* (54.42, 20 ind. ha^{-1}, 8.83 m^2 ha^{-1}) stood with lesser IVI values. In adjoining natural forests the decreasing order of IVI values for the tree was *Bauhinia retusa* 128.23, 180 ind. ha^{-1}, 7.22 m^2 ha^{-1}), *Mallotus philippensis* (70.70, 100 ind. ha^{-1}, 1.13 m^2 ha^{-1}) *Debregeasia salicifolia* (61.65, 100 ind. ha^{-1}, 3.34 m^2 ha^{-1}),

Boehmeria rugulosa (17.62, 20 ind. ha^{-1}, 0.43 m^2 ha^{-1}). In Chunakhala restored site diversity index of trees was (0.57) which is less in comparison to adjoining natural forests (1.20). Species similarity index of tree in Chunakhala restored site and adjoining natural forests was 57.15% (Table 3). Two species of tree was similar in both sites (Table 1).

The number of herbs in Sahastradhara restored site was 6 while in adjoining natural forests it was 11(Table 2). The main dominating herbaceous species in terms of Importance Value Index (IVI) with their corresponding density (individual ha^{-1}) and total basal cover (m^2 ha^{-1}) at Sahastradhara restored site was *Erianthus rufipilus* (133.17, 26000 ind. ha^{-1}, 1.42 m^2 ha^{-1}), *Chrysopogon fulvus* (41.20, 12000 ind. ha^{-1}, 0.36 m^2 ha^{-1}) *Micromeria biflora* (49.35, 8000 ind. ha^{-1}, 0.58 m^2 ha^{-1}) and *Eriophorum comosum* (47.60, 6000 ind. ha^{-1}, 0.41m^2 ha^{-1}) while minimum IVI was for *Eulaliopsis binata* (13.77, 2000 ind. ha^{-1}, 0.07 m^2 ha^{-1}) *Erigeron montanus* (14.91, 2000 ind. ha^{-1}, 0.11 m^2 ha^{-1}). In adjoining natural forests maximum IVI was represented by the seedlings of *Murraya koenighii* (52.77, 16800 ind. ha^{-1}, 0.26 m^2 ha^{-1}), *Adhatoda zeylanica* (seedling) (43.97, 16000 ind. ha^{-1}, 0.27 m^2 ha^{-1}), *Smilax zeylanica* (36.31, 8000 ind. ha^{-1}, 0.21 m^2 ha^{-1}) *Lepidagathis cuspidata* (seedling) (31.71, 6000 ind. ha^{-1}, 0.42 m^2 ha^{-1}) and minimum IVI was *Buddleja asiatica* (seedlings) (7.51, 2000ind. ha^{-1}, 0.02 m^2 ha^{-1}), *Pogostemon benghalense* (seedlings) (8.63, 2000 ind. ha^{-1}, 0.04 m^2 ha^{-1}) and *Eriophorum comosum* (9.73, 2000 ind. ha^{-1}, 0.06 m^2 ha^{-1}). In Sahastradhara restored site diversity index (1.44) was less as comparison to adjoining natural forests (2.20). Species similarity of herbs in Sahastradhara restored site and adjoining natural forests was 11.71% with only two similar species (Table 3). Sahastradhara restored site was less diverse in terms of adjoining natural forests of herbaceous diversity.

The number of shrubs of Sahastradhara restored site was 13 while in adjoining natural forests number of shrubs was 11 (Table 2). The main dominating shrub species in terms of Importance Value Index (IVI) with their corresponding density (individual ha^{-1}) and total basal cover (m^2 ha^{-1}) at Sahastradhara restored site was *Agave sisalana* (124.32, 4320 ind. ha^{-1}, 13.69 m^2 ha^{-1}), *Eupatorium adenophorum* (38.51, 2560 ind. ha^{-1}, 0.60 m^2 ha^{-1}), *Lantana camara* (31.88, 1920 ind. ha^{-1}, 0.97 m^2 ha^{-1}) and minimum IVI was *Ficus palmata* (4.51, 80 ind. ha^{-1}, 0.01 m^2 ha^{-1}), *Boehmeria platyphylla* (4.53, 80 ind. ha^{-1}, 0.01 m^2 ha^{-1}) and *Callicarpa macrophylla* (4.54, 80 ind. ha^{-1}, 0.01 m^2 ha^{-1}). In adjoining natural forests maximum IVI of shrub was *Murraya koenigii* (94.03, 4560 ind. ha^{-1}, 1.93 m^2 ha^{-1}), *Lantana camara* (89.31, 4080 ind. ha^{-1}, 1.89 m^2 ha^{-1}) *Adhatoda zeylanica* (43.14, 2480 ind. ha^{-1}, 0.59 m^2 ha^{-1}) and minimum IVI was of *Hypericum oblongifolium* (4.82, 80 ind. ha^{-1}, 0.01 m^2 ha^{-1}), *Pogostemon benghalense* (5.34, 80 ind. ha^{-1}, 0.04 m^2 ha^{-1}) and *Rubus biflora* (IVI 6.08, 160 ind. ha^{-1}, 0.04m^2 ha^{-1}). In Sahastradhara restored site diversity index of shrub (2.00) was more in comparison to adjoining natural forests (1.59). Species similarity of shrub in Sahastradhara restored site and adjoining natural forests was 50.00%. Six species of shrub was similar in both sides but Sahastradhara restored site was more diversed in case of shrub diversity.

The number of trees in Sahastradhara restored site was 9 as compare to 16 in adjoining natural forests. The main dominating tree species in terms of Importance Value Index (IVI) with their corresponding density (individual ha^{-1}) and total basal cover (m^2 ha^{-1}) of Sahastradhara restored site were *Acacia catechu* (71.56, 200ind. ha^{-1}, 1.50 m^2 ha^{-1}), *Grevillea robusta* (55.48, 100 ind. ha^{-1}, 3.46 m^2 ha^{-1}) *Jacaranda mimosaefolia* (45.67, 100ind. ha^{-1}, 1.14m^2 ha^{-1}) and minimum IVI was for *Boehmeria rugulosa* (10.15, 20 ind. ha^{-1}, 0.07m^2 ha^{-1}), *Cocculus laurifolius* (11.25, 20 ind. ha^{-1}, 0.19 m^2 ha^{-1}) *Syzygium cumini* (12.50, 20 ind. ha^{-1}, 0.32 m^2 ha^{-1}). In adjoining natural forests maximum IVI of tree was *Mallotus philippensis* (54.59, 160 ind. ha^{-1}, 14.98 m^2 ha^{-1}), *Bauhinia*

variegata (43.58, 100 ind. ha^{-1}, 12.89 m^2 ha^{-1}), *Jacranda mimosaefolia* (24.60, 60 ind. ha^{-1}, 3.59 m^2 ha^{-1}) and minimum IVI was for *Cocculus laurifolius* (6.12, 20 ind. ha^{-1}, 0.12 m^2 ha^{-1}), *Cordia dichotoma* (6.52, 20 ind. ha^{-1}, 0.32 m^2 ha^{-1}) and *Melia azedarach* (6.53, 20 ind. ha^{-1}, 0.33 m^2 ha^{-1}). In Sahastradhara restored site diversity index of trees (1.90) was less in comparison to adjoining natural forests (2.55). Species similarity of tree in Sahastradhara restored site and adjoining natural forests was 48.00% (Table 3). Only five species were similar at both sites (Table 2).

DISCUSSION

The phytosociological study is imperative to understand the structure and function of a particular vegetation community. The structure and distribution of trees, shrubs and other ground flora are very sensitive to changes within a short span of time and the major factors influencing these changes are bioedaphic including two factors that influenced growth performance of species in forestland, which are edaphic factors (soil texture, moisture content, bulk density, particle density, organic matter and nutrient content) and climatic factors (weather condition, pest attack and animal distribution, weed competition and growing space) (Hassan, 2007). These factors exert strong influences on plant development which in turn improve the micro-habitat by regulating the community structure and ecosystem functioning (Soni *et al.*, 1994; Leigh, 1965). Diversity of ground flora (herbs) is closely related with seasonal variables. Species diversity increases during spring season and declines thereafter. In summer season new species go on sprouting depending upon the root/seed stock in the soil and thereby adding to species in total resulted more diversity. During autumn and winter species number declined owing to adverse climatic conditions. In this way, Shannon diversity (H') varies season to season in case of herbaceous floral diversity (Shameem *et al.*, 2010). With the establishment of planted grasses, invasion by native species of herbs played an important role in increasing the diversity of forest communities in all mined lands (Bhatt, 1990; Soni *et al.*, 1994).

Importance value index (IVI) is a device to rank species in a community and often used to elucidate features of the community (Lamont *et al.*, 1977). The data on diversity index (Table 1, 2) reveals that at Chunakhala restored site, shrubs were found dominant with a little difference followed by herbs and the diversity index of tree species was found comparatively very

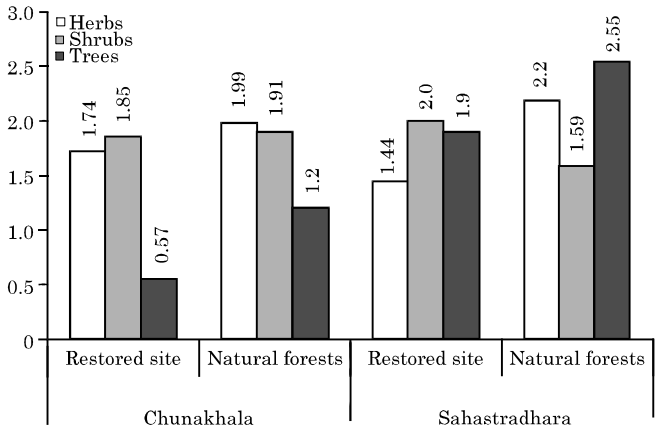

Fig. 1: Floristic diversity index of different study sites

less. In adjoining natural forest of Chunakhala, herbs showed slightly higher diversity index followed by shrubs and then trees. Figure 1 shows that the values of diversity indices of herbs and shrubs at Chunakhala restored sites have reached almost near to its natural forest. While in case of Sahastradhara restored site maximum diversity was shown by shrub species followed by tree and then herbs as compared to adjoining natural forest where diversity of different plant forms were found in the order of trees>herbs>shrubs. The present data of floristic structure states that shrubs showed higher diversity at Sahastradhara restored sites then that of natural forest. It proves the good establishment of the planted shrub species at there e.g., *Agave sisalana* (124.32). High IVI value of *Eupatorium adenophorum* (38.51) and *Lantana camara* (31.88) also show their invasion here and contribution in the high diversity index of shrubs. Trees of Sahastradhara restored site also showing the approaching values to its natural forest which shows that these tree species are most aggressive and happened to be most frequent and abundant in limestone mine areas (Masoodi, 1998). It can be seen in the graph (Fig. 1) this site is more diverse than the Chunakhala restored and natural forest sites.

In disturbed system where plant competition takes place, plant diversity first rises and then falls with increasing productivity. Verma (2003) reported the maximum diversity for trees followed by shrubs and then herbs while working in restored limestone mines in Mussoorie hills. He further reported the high diversity and low density of shrubs and trees as diversity index for shrubs and trees is negatively correlated with density. Masoodi (1998) reported that in limestone mine of Mussoorie region the plant community on restored site contained an important contribution not only from tree and shrub species but also from various herbaceous species. The importance of these species lies in the fact that they have not only spread to cover the open patches left at the time of restoration but have also set the long process of succession in motion. This shows that these species are most aggressive to be frequent and abundant in limestone mine areas. Margalef (1968), Odum (1969), Soni *et al.* (1994) and Shafi and Yarranton (1973) have suggested that species diversity should increase rapidly during the early successional stages and then decline somewhat near climax. Present study shows that after 21-22 years of early successional species used during restoration have started getting replaced (Masoodi, 1998). Tree species viz., *Grevillea robusta, Jacaranda mimosaefolia, Cocculus laurifolius, Toona ciliata, Syzygium cumini, Bauhinia retusa, Cupressus torulosa, Debregeasia salicifolia* have started invading both mine areas. Floristic diversity has been increasing in last 21- 22 years in Chunakhala as well as Sahastradhara restored mine areas and approaching to adjoining natural forests.

Natural invasion of trees into revegetated sites can be affected by the types of plant species already growing in the site and as well as by resource availability. The establishment of tree plantations in degraded areas may facilitate regeneration of native species that could not otherwise establish in open micro-sites or in competition by herbaceous species. This increase in biodiversity is of great importance due to the functional role, especially of soil fauna, for soil properties and self-regulation potential of intensive forest ecosystems (Rouhi-Moghaddam *et al.*, 2007) . Gibson *et al.* (1985) reported that natural re-vegetation by tress was a complex process controlled primarily by dispersal mechanisms of the tree species. Some plant species have been observed to facilitate the invasion by eliminating the competition and attracting the seed carrying animals (Werner and Harbeck, 1982). Establishment of diverse plant cover leads to the development of diverse food webs both above and below ground and thus allows invasion of variety of other useful plants (Yue *et al.*, 1994). According to Rosiere *et al.* (1989) the seeding of native plants especially late seral species hastens the natural colonization in limestone mines. Soni *et al.* (1994) reported that the mixture

of native species has not only improved the soil fertility status and productivity capacity of the spoil material but also favors the invasion of various natural invaders.

CONCLUSION

Results of the study led to the conclusion that both the mine sites have restored and primary colonizing plant species are thriving successfully on the earlier derelict sites. The diversity indices of shrubs at Chunakhala restored site is nearly similar with nearby natural forests (1.85 and 1.91, respectively) and showing similarity index of 57.15. Total trees number is also higher at the Chunakhala restored site with double the total basal area than the natural site. It shows fast recovery of the through restoration process. The status of trees diversity is lower as compared to the natural forest with 57.15 similarity index. Sahastradhara natural forest and restored site both are comparatively more diverse than the Chunakhala natural and restored sites. In case of Sahastradhara sites, shrubs diversity index is higher for restored site. Total basal area of shrubs is 3.4 times higher for the restored site. It indicates the effectual distribution of understory vegetation on the degraded site as in early succession tree dominance is low. Biodiversity evaluation of restored sites and their comparison with the nearby natural forests establish the success of these 21-22 old ecological restoration interventions.

Ecorestoration studies provide an insight of the ecological processes and help to understand many structural aspects and functions of ecology viz., dominance, invasion, conservation, succession, competition, ecosystem dynamics and equilibrium etc. Successful restoration of floristic diversity in mining areas not only facilitates the natural process of speciation but also becomes a source of germplasm of various species. It improves all environmental conditions aesthetically including economical aspects.

ACKNOWLEDGMENT

We are thankful to Director, F.R.I. Dehradun, for providing his permission and other infrastructural facilities.

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