Species selection for improving disturbed habitats in Western India

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A study was conducted to select plants species for restoration of a habitat disturbed by mining in central Gujarat. Species for restoration were selected through a systematic procedure that involved IVI and regeneration values for tree species in the mine forest area; and growth, productivity, and adaptation to terrain and soil types for species in plantations. Shrubs were selected based on relative index and grasses were selected based on relative abundance. Although mine forest area generally had more diversity than plantations, dump areas and beneficiation plant sites, some tree species performed better in plantations. The top ten tree and grass species, and all the six shrub species were selected for restoration. Since soils of dump were of similar nature as that of the forest area, the findings will be helpful in faster restoration of the degraded habitats with initial human facilitation. Aftercare and monitoring has also been suggested to enhance the recovery process.

DISTURBANCE to natural habitats due to opencast mining, which inevitably requires clearing of vegetation, is a common phenomenon. In disturbed habitats, the natural recovery takes time through colonization of plant and animal species[1], and can be accelerated through human intervention.

Till recently, not much attention was paid to restoration of the habitats. The recent awareness, followed by stringent law enforcement has generated consciousness about the environment. Restoration has been attempted on an experimental scale in various parts of the country[2–4] and its implementation for the whole area has also started at some locations. In some cases the plantation of exotic and horticulture species has also been considered as restoration, while in other cases, e.g. Neyveli, the degraded land has been made productive and changed to agricultural land.

Restoration is the recreation of entire communities of organisms, closely modelled on those occurring naturally; while reclamation refers to any deliberate attempt to return a damaged ecosystem to some kind of productive use or socially acceptable condition short of restoration[5]. It would appear that in many cases, it is reclamation rather than restoration which is attempted. Restoration needs knowledge of indigenous biological resources for understanding the species response to micro-environmental features and edaphic conditions[6–8]. The information on these aspects not only helps in selecting species adapted to local conditions[9] but also in the fast recovery of the ecosystem when such species are planted there[10]. This article presents the outcome of a study that included these aspects to help in ecological restoration of a disturbed site.

The Ambadungar hills in Vadodara District, Gujarat have been disturbed due to mining since 1965. The area with dry deciduous forests has the only minable fluorspar (CaF_2) deposits in the country. To undertake the mining activities, most of the forests on the hills were cleared. Presently, dumping is being done in well-vegetated valleys on the western side of the mines which has adversely affected the vegetation. A study was carried out to compare the plant diversity and abundance in disturbed and undisturbed areas and select plant species based on a set of criteria, in restoring the disturbed sites.

Study area

The Ambadungar hills are situated at the eastern termination of the Vindhyan range and are surrounded by Deccan trap basalt (Figure 1). The mines are located at 74°4′N and 22°E in Chhotaudepur taluka in Vadodara district. The mines' lease area is about 620 ha and is situated on the Ambadungar hills at an elevation of 580 m above mean sea level. The slope of the hill is steep to very steep. Mining has been done in 15 ha and 15.5 ha has been used as dump. The existing total estimated mineral reserve is around 11 million tonnes. The ore to waste ratio is 1 : 4 which might increase to 1 : 7 with increasing depth. The mines' lease area includes the following: (i) Forest area (FA): 585 ha, where mining activities have not yet been taken up and has natural vegetation in some parts. (ii) Active dump (AD): where waste and topsoil from the mining area is being dumped. (iii) Old dump (OD): where the waste and topsoil was dumped in the past. Only *Acacia senegal* has been planted here. (iv) Beneficiation plant (BP): located near the base of the hill, to extract fluorspar from the ore. (v) Plantations (P): carried out in 73 ha, on parts of FA from 1987 to 1995 by a mining agency. These have multiple species, as given later.

The soils of the area are loamy with some proportions of silt and clay. The depth varies from shallow (0–25 cm) and medium (26–50 cm) to moderately deep (51–75 cm).

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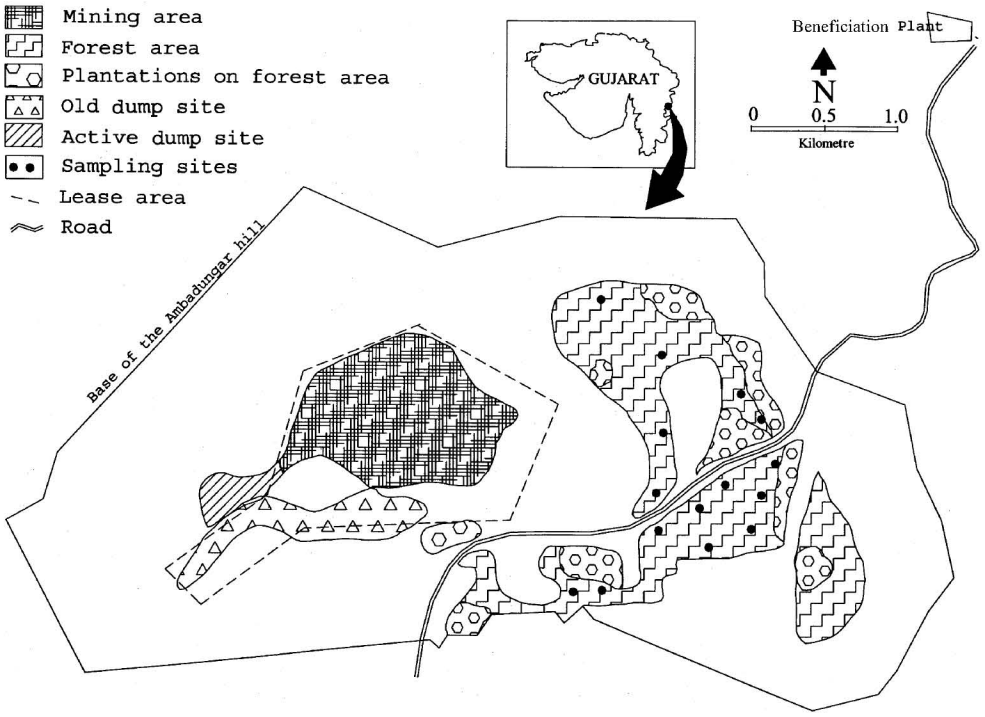

Figure 1. Map of Ambadungar mining lease area.

Most areas have medium-depth soils. About 60% of the area has moderate-to-good water holding capacity.

The climate is sub-humid. Summer (March–June) temperature reaches a maximum of 43°C and in winter (November–February) the temperature is as low as 6°C. Average annual rainfall is about 1000 mm, mostly during July to September with an average of 35 rainy days per year. The remaining 8–9 months are dry.

Methods

A reconnaissance survey was undertaken in July 1996 to decide sampling methods and select the study sites.

The study was conducted in FA, OD, AD, BP and P. Vegetation in FA was studied in fifteen stratified random belt transects, each 50 m × 6 m. The stratification was based on the habitats and major topographic variations. In each transect data on trees (> 20 cm GBH-girth at breast height) basal girth, height, canopy height and canopy width, and regeneration (plants < 10 cm GBH) were recorded. Shrub species and their abundance were recorded on these transects, while in case of grasses, the frequency of occurrence was noted.

BP and AD had only grass cover that was estimated at 10 m intervals along five line transects in each of them. Since grass cover on AD and OD was low, it was estimated qualitatively, i.e. rare, common and abundant; and an abundance rating (AR) was given. The rare species was rated as 1, while the common and abundant species were given a score of 2 and 3, respectively.

Some of the species grown in P did not occur in the FA. It was, therefore, desirable to investigate their adaptation, growth and productivity to assess their suitability in restoration. For this, GBH, height and canopy of every alternate tree in alternate rows of seven plantations were measured and habitat parameters, viz. terrain (flat, slope, valley, stream or riverbeds) and soil depth (shallow, medium, deep) were recorded.

Species selection from forest

Tree species for restoration were selected in two phases. In the first phase, the top 15 species were selected based on Importance Value Index (IVI). Ranking was given to each species based on the IVI[11]. IVI was calculated as a sum of relative density (RD), relative frequency (RF), and relative dominance (RDO).

During the second phase of selection, regeneration potential was included. Trees represented by more than 15 individuals in the regeneration stage were ranked 1, and species having five individuals in the regeneration stage were ranked 2, while those having no regeneration were ranked 3. Adding IVI and regeneration ranks, the top ten tree species were selected for restoration.

Shrub species were selected using relative index (RI) computed as a sum of RD and RF. For grasses, only RF was calculated in FA, and AR for species observed in BP, OD and AD.

Species selection from plantation

Tree species in P were selected based on their growth, productivity and adaptation. The growth was estimated using size index modified from Aldon and Springfield[12], as

Size index = Tree height (cm) × GBH (cm).

Productivity potential of tree species was estimated using Canopy index[13].

Canopy index = (Avg. canopy height + Avg. canopy width) × no. of sample trees.

Height was estimated by using a marked pole.

Growth and productivity rates were calculated by dividing the size and canopy indices with age of the tree species. The species were given rankings for their productivity and growth rates.

For evaluating adaptation, the species growing on the slopes were ranked 1, on flat terrain were ranked 2, while those in valley, streambed or riverbed were ranked 3 and 4 respectively. The species growing on shallow soils were ranked 1, while those on medium and deep soil were ranked 2 and 3, respectively.

Adding the ranks for growth, productivity, terrain and soil, the top ten species were selected. Some species were included based on their properties to enrich the soil.

Results

Species richness and abundance

Plant species richness was maximum in FA with an overall 52 species, that included 29 tree, 6 shrub and 17 grass species (Annexure, Tables 1 and 2). Tree species in FA were 2.5 times more than in P, which had only trees belonging to 12 species (Table 3). BP, OD and AD had 19, 13 and 12 respectively, grasses and sedges (Table 2).

Table 1. Relative density and relative frequency of shrub species recorded in Ambadungar mine forest

Species	RI	Rank
Woodfordia fruticosa	25.84	1
Helicteres isora	19.91	2
Nyctanthus arbor-tristis	16.25	3
Grewia abutilifolia	14.79	4
Flacourtia indica	12.24	5
Cassia auriculata	10.87	6
Total	100.00	

RI, Relative index.

Four tree species were common to the FA and P. Of these, *Gmelina arborea*, *Diospyros melanoxylon* and *Albizia lebbeck* performed better in P only. On the other hand *Tectona grandis* performed well in both.

Diversity of shrub species was rather low in the study area as only six shrubs species were recorded in FA and none on BP, OD, AD and P.

Overall, 22 grass and sedge species were recorded. BP had more species (19) than the FA (17) and the dumps (OD 13 and AD 12). RF in FA ranged from 1.39% to 11.63%. Only three grass species had more than 10% RF. These were *Dactyloctenium aegyptium* (11.63%), *Eleusine indica* (10.80%) and *Themeda* sp. (10.53%) (Table 2). Except one species (*Pennisetum* sp.), the grass species in BP were either common or abundant.

A comparison of ARs of grasses among BP, OD and AD showed that 52.63% species were abundant at BP, while at the OD and AD it was 23.08% and 18.18% respectively. *Cyperus corymbosus*, the only sedge species recorded, was widely distributed among the three areas followed by *Chloris virgata*, *D. aegyptium* and *Digitaria marginata*.

Tree selection

In FA, *T. grandis* had maximum IVI (Table 4). Out of the total 29 species, 7 species had an IVI greater than 5. Rest of the species had IVI ranging from 0.38 to 3.79.

The top 15 species with higher IVI values were selected for regeneration studies. In this category, 8 species had more than 15 individuals in regeneration class, 5 had more than 5, while 2 did not have any individual. Among the top 10 species selected based on the IVI and regeneration ranks, *T. grandis* was the topmost species while *Dalbergia latifolia* was the last.

In plantations, 12 tree species were recorded. The age of tree species (years after plantation) ranged from 3 to 6 years. *G. arborea* was the fast-growing species with maximum growth rate of 4097 cm^2/year while *T. grandis* gained maximum productivity of 48 cm^2/year (Table 3).

When adaptation to terrain and soil depth was included in the selection parameters, *A. senegal* and *D. melanoxylon* shared the top rank.

Shrub selection

The RI of shrub species in the FA ranged from 10.87 to 25.84%. *Woodfordia fruticosa* had maximum RI followed by *Helicteres isora* and *Nyctanthus arbor-tristis,* while *Cassia auriculata* had the minimum RI (Table 1). All the six species found were recommended for use in restoration.

Table 2. Relative frequency (forests) and abundance rating of grass species recorded in FA, BP, OD and AD at Ambadungar

Grass species	MF		BP	OD	AD	Total	
	RF	Rank	AR	AR	AR	AR	Rank
Apluda mutica	8.31	5*	3	1	–	4	5
Aristida setacea	–	–	–	3	3	6	3*
Brachiaria mutica	–	–	–	2	1	3	6
Chloris barbata	2.77	14	3	2	1	6	3*
Chloris virgata	4.15	11	3	3	2	7	2*
Cyperus corymbosus	5.82	7*	3	3	3	9	1*
Cyperus difformis	4.71	10	2	1	1	4	5*
Cyperus eleusiniodes	5.26	8*	3	–	–	3	6
Cyperus iria	6.09	6*	3	–	–	3	6
Cyperus sp.	3.05	13	2	–	–	2	7
Dactyloctenium aegyptium	11.63	1*	3	2	2	7	2*
Digitaria marginata	5.82	7*	3	2	2	7	2*
Echinochloa colona	4.99	9*	2	–	–	2	7
Eleusine indica	10.80	2*	2	2	1	5	4*
Fimbristylis sp.	–	–	–	1	1	2	7
Panicum miliaceum	–	–	2	–	2	4	5
Paspalidium punctatum	3.32	12	2	1	–	3	6*
Pennisetum sp.	1.39	15	1	–	–	1	8
Setaria tomentosa	8.59	4*	3	1	1	5	4*
Sporobolus pallidus	–	–	2	–	–	2	7
Sporobolus sp.	2.77	14	2	–	–	2	7
Themeda sp.	10.53	3*	3	–	–	3	6

MF, Mine forest; RF, Relative frequency; AR, Abundance rating; BP, Beneficiation plant; OD, Old dump; AD, Active dump. *Species selected for restoration.

Table 3. Growth, productivity, terrain and soil ranks of tree species in Ambadungar plantations

Tree species	Age	Growth rate		Productivity rate		T	S	Total
		GR/Y	Rank	P/Y	Rank	Rank	Rank	Rank
Acacia catechu	4	1959	11	28	8	2	1	22
Acacia nilotica	6	2063	10	26	9	2	1	22
Acacia senegal	5	3661	2	35	4	2	1	9*
Albizia lebbeck	3	3049	5	31	6	2	1	14*
Cassia siamea	6	1516	12	31	6	1	2	21*
Dalbergia sissoo	3	2690	7	44	2	1	2	12*
Delonix regia	6	2240	9	35	4	2	3	18*
Diospyros melanoxylon	3	3379	3	42	3	2	1	9*
Eucalyptus sp.	5	2983	6	29	7	1	1	15*
Gmelina arborea	5	4097	1	26	9	2	3	15*
Peltophorum pterocarpum	5	3283	4	33	5	2	3	14*
Tectona grandis	3	2663	8	48	1	2	3	14*

GR/Y, Growth rate/year; P/Y, Productivity/year; T, Terrain; S, Soil. *Species selected for restoration.

Grass selection

The top 10 grass species were selected from the FA and another 10 from BP, OD, and AD together. Since some grass species were common, overall 15 species were selected (Table 2).

Discussion

Plant species diversity at tree and shrub levels was more in FA than in P. This is natural because plantations are generally monocultures or at best include few species of interest and are single layered. Forests, on the other hand, grow with natural succession; have stratification resulting in higher species diversity of not only plants but also animals[14].

The grass frequency and diversity was more at BP because it was old compared to OD and AD. The negligible canopy and shallow soils of BP also favoured more growth of grass than in FA.

The parameters used for selecting a species were decided in order to gauge their adaptation and robustness to grow in difficult conditions. Inclusion of more than one parameter

ensured that even if some species scored equal points on one parameter, the difference in scores on other parameters helped in selecting the better species. For example, tree species in plantations showed similarity in productivity but there was a variation in growth rate.

Similarly, sampling in all the areas (FA, OD, AD, P and BP) helped in developing a comprehensive list of species based on their performance in diverse habitats. Only 12 tree species were grown in P, 8 of which did not occur in FA. On the other hand, a relatively large number of species in the FA helped in providing more options for the species selection. The cumulative list of 20 tree species, 10 each from FA and P, provided best performing local species in the vicinity, to boost natural colonization. Inclusion of grass, shrubs and tree species ensured that restoration takes place at different strata as in a natural forest.

Natural succession commences with grasses among the higher plant groups, as is apparent in the present case with only grasses found both on the AD and OD. Introducing the grass species from the BP can enhance succession rate on OD and AD. Promoting selected native shrub and grass species on the periphery of dumps and on streambed can act as vegetative filter to reduce soil and water pollution in the surrounding areas as observed by Schwer and Clausen[15]. Shrubs are more effective in halting runoff and erosion[16] than the agroforestory crops. Therefore, in this study, native shrub species are suggested for the dumps as the first phase of restoration.

One of the parameters considered to select plant species was the slope gradient[17]. Two shrubs (*N. arbor-tristies* and *Grewia abutilifolia*) and three grasses (*Setaria tomentosa*, *Themeda* sp. and *D. aegyptium*) were found abundant on the slopes. Therefore, these species should be grown on the dump slopes.

The soils of both the AD and OD were of similar nature as that of FA or P[18]. Moreover 60 cm of the topsoil is stocked separately for spreading it on the dumps during

Table 4. IVI and regeneration ranks of tree species in mine forest at Ambadungar

Species	IVI		Regeneration rank	Total rank
	Value	Rank		
Tectona grandis	13.58	1	1	2*
Mitragyna parvifolia	9.40	2	1	3*
Anogeissus latifolia	9.12	3	1	4*
Adina cordifolia	7.93	4	2	6*
Lannea coromandelica	7.64	5	2	7*
Miliusa tomentosa	5.91	6	1	7*
Bridelia retusa	5.09	7	1	8*
Schleichera oleosa	3.78	8	1	9*
Elaeodendron glauca	3.77	9	3	12
Garuga pinnata	3.69	10	2	12*
Wrightia tinctoria	3.61	11	1	12*
Terminalia bellirica	2.62	12	2	14
Terminalia tomentosa	2.61	12	2	14
Dalbergia latifolia	2.54	13	3	16
Anogeissus pendula	2.19	14	1	15

IVI, Importance Value Index. *Species selected for restoration.

Table 5. Tree species suggested for plantation on dumps

Species	From forest area	From plantations
Tectona grandis	●	
Mitragyna parvifolia	●	
Anogeissus latifolia	●	
Adina cordifolia	●	
Lannea coromandelica	●	
Miliusa tomentosa	●	
Bridelia retusa	●	
Schleichera oleosa	●	
Garuga pinnata	●	
Wrightia tinctoria	●	
Acacia senegal		○
Albizia lebbeck		○
Cassia siamea		○
Dalbergia sissoo		○
Delonix regia		○
Diospyros melanoxylon		○
Eucalyptus sp.		○
Gmelina arborea		○
Peltophorum pterocarpum		○
Tectona grandis		○

Annexure. Importance Value Index (IVI) of trees recorded in Forest Area (FA) of Ambadungar mines

Species	IVI	Rank
Tectona grandis	13.58	1*
Mitragyna parvifolia	9.40	2*
Anogeissus latifolia	9.12	3*
Adina cordifolia	7.93	4*
Lannea coromandelica	7.64	5*
Miliusa tomentosa	5.91	6*
Bridelia retusa	5.09	7*
Schleichera oleosa	3.78	8*
Elaeodendron glauca	3.77	9*
Garuga pinnata	3.69	10*
Wrightia tinctoria	3.61	11*
Terminalia bellirica	2.62	12*
Terminalia tomentosa	2.61	12*
Dalbergia latifolia	2.54	13*
Anogeissus pendula	2.19	14*
Morinda tinctoria	2.10	15
Cassia fistula	1.95	16
Holarrhena antidysenterica	1.89	17
Diospyros melanoxylon	1.58	18
Ficus carica	1.47	19
Holoptelea integrifolia	1.39	20
Butea monosperma	1.22	21
Trema orientalis	1.10	22
Albizzia lebbeck	1.07	23
Alangium salviifolium	1.05	24
Derris indica	0.52	25
Bauhinia racemosa	0.41	27
Eviolaena stocksii	0.41	27
Gmelina arborea	0.40	28
Total	100.02	

IVI, Importance Value Index.
*Species selected for regeneration studies.

restoration. Therefore, the selected plant species will successfully grow on dumps. A small part of OD has already been successfully planted with *A. senegal*. Further, to enhance the productivity, use of FYM and VAM fungi is suggested[19]. To increase the fertility level of dump, growing leguminous plants would be more useful, as they supply nitrogen to the root zone in mine spoil[20]. *Acacia* spp. and *A. lebbek* are some of the species that have high nitrogenous activity in root nodules[21]. Therefore, these tree species are suggested to grow on dumps as well as in the degraded areas. In addition to these, *Derris indica* is considered a promising species for overburden of mining areas[22] and should be planted on the dumps to enrich the soil. The findings also suggest that tree species selected from FA may perform well when planted on dumps as indicated by better growth and productivity of *G. arborea*, *D. melanoxylon* and *A. lebbeck* P than in FA. The list of tree species suggested for plantation is given in Table 5.

While restoration of the habitats is undertaken, certain steps should be followed. The basic requirements in restoration are water management to promote perennial species and protection from grazing and cutting. In addition, ecological study at regular intervals is needed to monitor the survival and growth of plant species and to find out the effects of various plant species on the habitat conditions[23]. Further, monitoring of avifaunal communities may also be important in understanding the overall effects of restoration work. Bird communities are good indicators for monitoring environmental changes[24]. Most of the bird species have relatively short lifespan; consequently they are likely to show quick responses to environmental changes[25]. The baseline data on birds collected during the present study[19] can be used for monitoring the environmental changes in future.

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