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Restoration of Forest and Associated Ecosystem Services of Backfilled Open Cast Coal Mines at Dhanbad, Jharkhand, India

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ABSTRACT
Backfilled open cast coal mines are subjected to reclamation and restoration as per the mining and mine closure policies of India. The present paper discusses a case study on restoration of 15 acres land of backfilled open cast mine in the Bharat Coking Company Limited (BCCL) located at Barora, Dhanbad district, India. Through this study an attempt has been made to quantify return of ecosystem services in terms of growth rate and survival rate of native species planted, nutrient replenishment, biodiversity conservation with insect diversity as an indicator. The paper briefs the stepwise methodology used for ecological restoration and results on early success indicators of successful reclamation.

Key Words: Backfilled open cast coal mines, restoration, biodiversity

INTRODUCTION

Coal mining dates back to 18th century and is the most abundant fossil fuel in India. Globally, India is the second largest producer of coal, after China. During 2020, the coal production in India was estimated at about 723 Mt and further, Indian Govt. mandated Coal India Limited (CIL) to replace its imports by at least 100 Mt using domestic coal in the fiscal year 2020-21 (IEA 2020). Coal India Limited (CIL) has been a corporation for coal mining since 1975, where initially government of India took over private coal mines (Jain and Doddamani 2013). Currently, CIL appeared as the largest coal mining company in the world having a total of 364 mines including 166 underground, 180 opencasts and 18 mixed mines. However, more than 90 per cent of total production came from opencast mines only (IEA 2020). Bharat Coking Coal Limited (BCCL), Dhanbad, Jharkhand is one of the major coalfields of CIL in India and where the current study on restoration has been implemented.

During open cast mining overburden (OB) removal, dumping and backfilling operations generate huge amount of mine spoils. Reclamation of the mine spoils/OB becomes challenging because soil physical constraints (texture, structure, water holding capacity, stability), soil composition and climate act as limiting factors (Agrawal et al. 1993). Eco-restoration of these OB dumps is an integral part of Environment Management Plan (EMP) of any coal mining project. The eco-restoration of coalmine OB dumps in developing countries is mostly done by application of topsoil cover and liming. It is assumed that ecosystem services (MEA 2005) of the restored land will recover and it is pertinent that site specific techniques are used for replenishing the nutrient deficiencies of the soil, enhance the survival and growth of the plants (Burger et al. 2017). Restoring the land to a forest community representing the geographical location is desirable but not always feasible. Species native to the region which are capable of surviving in harsh environmental conditions, for which horticultural techniques known and also available with nurseries at vicinity gets prioritized. Our restoration activity has emphasized usage of mycorrhizal inoculum (Kalucka and Jagodzinski 2016) that aids species in nutrient uptake and enhance survival prospects. A successful restoration requires re-establishment of soil properties and ecosystem services (Walker 2005).

Ecological restorations directly increase the provisioning, regulating, cultural and supporting services (Benayas et al. 2009). Appropriate quantification of these services may lead to a favourable policy environment encouraging restoration of degraded land. This is more pertinent at a time when global commitments like the Bonne Challenge, declaration by UN as 2020-30 as decade of restoration and call for Land Degradation

Neutrality (LDN) by United Nations Convention on Combating Desertification (UNCCD) been made. In this paper, an account of return of ecosystem services post restoration on a coal mine OB in Jharkhand, India is presented.

MATERIALS AND METHODS

Study area

The restoration of 15 acres of land (60,703 m^2) was undertaken by TERI SAS at Muraidih (23° 48' 49" and 23° 47' 30" latitude, 86° 15' 20" and 86° 13' 30" longitudes) in Barora Area (Fig. 1), a coalfield belongs to Jharia Coalfields (JCF) under BCCL. It is located in the state of Jharkhand in Dhanbad district (23°37'3" N and 86°6'30" E) and at an elevation of 225 meters above mean sea level. The JCF has been the largest and most extensively developed coalfield in India that has been mined for over a century (Kumar and Singh 2016) and is under active stages of reclamation and restoration. The restoration site was delineated into five zones *viz*., Plantation with forest trees, Fruit bearing trees, Medicinal plants, Vegetables and a Wetland. Species planted in each of the zones are presented in Table S1.

The approach

A survey of forests around Muraidih was undertaken to select a reference site. Balmi Reserve, Forest a 3.25 sq km protected area under the Stare Forest Department, Govt of India, at distance of 25 km from the project site was chosen for vegetation analysis. It was undertaken by placing eight random quadrats at distance of 100 meters from each. Quadrats of 1m x 1m, 2.5m x 2.5m and 5m x 5m were used for herbs, shrubs and trees, respectively. The quadrate size for trees was determined after plotting a Species Area Curve. Importance Value Index (IVI) was calculated to determine dominant species (Misra 1968).

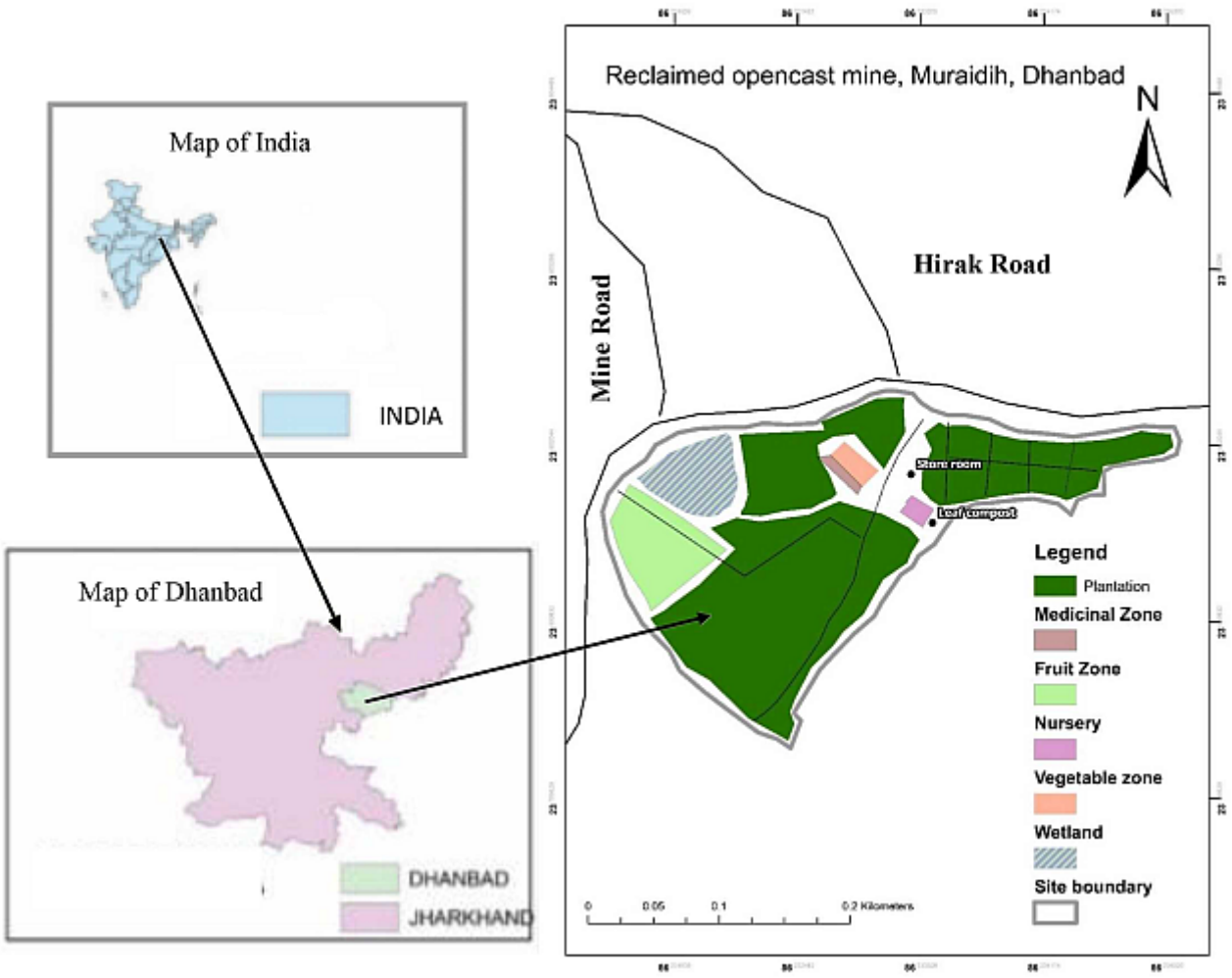


Figure 1. Study area map location and areas of interventions

Development of onsite nursery was initiated after consultation with local nurseries at Amghata and Gorathi regarding seed availability as well as supply of healthy seedlings. The pot culture germination tests were conducted on 19 shortlisted species (Table S2). Germination tests of preferred species were done in soil samples from Balmi Reserve Forest and Muraidhi coal site. The seeds procured from BCCL were subjected to pre-sowing treatment before germination test. Soil tested for germination for three sample types *viz*., blank (B), with Mycorrhize (M), and soil with cow dung as manure (SMC) in a ratio of 1:1:1.

At the very first year of restoration, seed balls made of grass seeds (*Stylosanthes hamata*), cow dung and soil were spread to improve the existing soil condition and enhance the Carbon and Nitrogen content. While germination tests were conducted to determine the survival prospects of the species contents, restoration was undertaken in two phases with seedlings of six readily available species (*Shorea robusta*, *Bauhinia variegata, Gmelina arborea, Dalbergia sissoo*, *Aegle marmelos, Terminalia arjuna*) from the local nurseries. During first phase 5 acres of land were subjected to plantation followed by balance 10 acres in second phase. Plantations were made on 2m x 2m pits with a spacing of 5m. Drip irrigation method was employed to water the plants and special attention was given to cleaning of airborne coal dust from the seedlings. Seedlings devoid of mycorrhizal applications are taken as control for comparison of growth of seedlings.

Monitoring of ecosystem services

The restoration of ecosystem services was monitored through soil health, growth of seedlings, insect diversity as indicators of biodiversity and microbial activity.

Soil Health

The parameters of soil health were investigated for the period 2015 - 2017 through sampling at restoration site and secondary literature on similar initiatives in the region. The soil samples were collected from a depth 0-10cm following coning and quartering method (Campos and Campos 2017). The processed samples were then analysed for bulk density, pH, electrical conductivity, organic carbon, nitrogen, phosphorus, potassium and sodium (Singh et al. 2007). Heavy metal analysis for soil samples, cow dung and leaf manure were under taken using Atomic-absorption spectroscopy (AAS). Grab sampling method was used to collect water samples followed by determination of pH, electrical conductivity, alkalinity, hardness, nitrate, sulphate, and heavy metals using standard methods (Eaton et al. 2005).

Biodiversity

The rapid biodiversity monitoring was conducted post plantation and insect diversity was considered as a primary indicator of revival of ecosystem services. Collection and trapping techniques involved were sweeping net, pitfall trap, pan trap, flying barrier trap, Winkler bag suspended and light trap, as well as manual collection (da Rocha et al. 2010). Based on observations, several biodiversity measures such as Simpson diversity, evenness, similarity index, Shannon-Wiener diversity index and species evenness were calculated for restored (RS) and non-restored site (NRS) prior to comparison.

Plant growth response

The productivity of the forest restoration was quantified by plantation growth and survival. Growth of each tree species was monitored considering first plant of every row planted at the site. This was taken as a representative of the whole sample used for analysis. Growth of flora was monitored every month during August, 2016 to January, 2018. The survival rate of the representative population was also monitored simultaneously.

Microbial diversity

The diversity of soil microbes was assessed by pour plate technique followed by streaking plate method in simple nutrient agar. (Gerdemann and Nicolson 1963, Douds and Millner 1999). The media prepared for assessment of microbial growth was Luria Bertini broth (Sezonov et al. 2007) that was spread, streaked and incubated. Three soil samples were taken for analysis: 1. Degraded (D) 2. Restored soil (RC) 3. Restored soil with mycorrhiza (RM).

Samples were first inoculated in differential media, Luria Bertani Broth (in triplicates) for 48 hours prior to which colonies were picked and purified using streaking technique. After the colonies were isolated, they were inoculated on various selective media in triplicates. Selective media

includes Actinomyces Agar, Thiobacillus Agar, Inorganic Salt Medium, Asparagine Nitrate Medium and Starkey's Sulphate Reducing Agar. Streaking technique was employed for purification of colonies.

RESULTS AND DISCUSSION

Importance Value Index (IVI)

Importance Value Index (IVI) for Vegetation Analysis at reference site, Belmi Reserve Forest revealed *Shorea robusta* as the most dominant species with an IVI of 132.815 followed by *Diospyros melanoxylon, Cassia siamea, Semecarpus anacardium, Aegle marmelos* and *Sida acuta* (Table 1). Our findings were very similar to an earlier study conducted at Dalma wildlife sanctuary in Jharkhand which reported the order as *Shorea robusta, Buchanania lanzan, Diospyros melanoxylon* and *Cleistanthus collinus* as dominants (Lal et al. 2019). The Shannon Weiner index of trees, shrubs and herbs were 1.48, 1.99, 1.80, respectively.

Germination test

The pot culture germination experiment was conducted on 19 species on OB at project site (Blank), soil from reference site and project soil inoculated with mycorrhizae of which a total of 8 germinated (Table 2). It was observed that six species in Muraidih soil (Blank) and five species in Balmi Reserve Forest soil responded in germination test. In contrast to blank soil, eight species germinated in soil samples inoculated with mycorrhizae from both the regions viz., Muraidih and Balmi. Only four and three species grew respectively in soils from Muraidih and Balmi Reserve Forest, when soil was mixed with mycorrhizae and cow dung.

Restoration of ecosystem services

Soil health

Soil Organic Carbon (SOC) of post plantation land was found to be 2.4 times more than the pre plantation indicating the overall improvement of soil health. SOC is known to affect plant growth both as a source of energy and nutrient availability through mineralization. SOC compounds such as polysaccharides help mineral particles to form aggregates. This increases the stability of the soil structure making it resistant to erosion. It also acts as the main source for the beneficial soil microorganisms. Nitrogen fixation for plants in a sustainable ecosystem primarily depends on nitrifying and denitrifying bacteria. These bacteria need an optimum pH to survive and perform efficiently in the range of 5-8 pH and this range of pH was observed at the restored site (Table 3).

Soil nitrogen showed improvement from 167kg/ha at pre plantation to 449 kh/ha in post plantation. The soil nitrogen was 68.45 kg/ha prior to restoration at the site, slightly lower than earlier study (89.24 kg/ha) (Rai et al. 2011). The site possibly gained more nitrogen due to addition of Cow dung as manure and the soil type had higher quantity of mineralizable materials (Rai et al. 2011).

Reuses of plant debris as compost not only introduce organic matter (OM) in soil but also reduce waste generation at project site. In addition, it also contributes to recycling of heavy metals within the restored soil or restricting heavy metals within the source. It was therefore pertinent to measure the heavy metal contents in leaf manure (Table 4). No specific trend was found in terms of selected heavy metal (Cr, Cd, Pb, As and Ni) concentrations in different phases of restoration activities. However, span of 2-3 years is not enough to get a clear picture about fate of heavy metals in soil due to restoration activities.

Water quality

The physico-chemical parameters of OB water were analysed and compared with standards of WHO (1977) and IS: 10500 and studies conducted earlier (Rai et al. 2011). It was observed that only the pH of the water sample is well within the range as per IS standards, else, all other values for rest of the parameters are low and well within the desired permissible limits (Table 5). The electrical conductivity, however has exceeded from the set value of 0.750 mS/m. The higher values have been observed possibly due to upward movement of several salts and also deposition of airborne coal particles at the site (Rai et al. 2011).

The water source for drip irrigation at the site depicted that heavy metals were within the limits (Table 6) according to ISO-14000 Standard Schedule, 2012. Such water quality ensures that irrigation activities are not causing any additional toxicity to the plants.

Table 1. IVI of species at reference site Balmi Reserve Forest

Tree species	N	Total area (m^2)	D	RD	F	RF	Do	RDo	IVI
Shorea robusta	11	200	0.055	44	0.625	29.412	7.007	59.403	132.82
Diospyros melanoxylon	6	200	0.03	24	0.75	35.294	1.335	11.318	70.61
Cassia siamea	5	200	0.025	20	0.375	17.647	0.749	6.351	44.00
Sida acuta	1	200	0.005	4	0.125	5.882	0.188	1.593	11.48
Semecarpus anacardium	1	200	0.005	4	0.125	5.882	1.361	11.536	21.42
Aegle marmelos	1	200	0.005	4	0.125	5.882	1.156	9.798	19.68
Total	**25**		**0.125**		**2.125**	**100**	**11.796**	**100**	

D: Density, RD: Relative Density, F: Frequency, RF: Relative Frequency, Do: Dominance, RDo: Relative Dominance, IVI: Importance Value Index

Table 2. List of species subjected to germination test

Species	Family	Gemination (cm)					
		Muraidih site			Balmi site		
		B	M	SMC	B	M	SMC
Aegle marmelos	Rutaceae	6	NG	NG	7	8.5	5.5
Annona squamosal	Annonaceae	17	NG	NG	NG	NG	4
Albizia odoratissima	Fabaceae	1.5	10	NG	3	12	NG
Bauhinia purpurea	Leguminosea	NG	4	1	NG	NG	1
Ceiba pentandra	Malvaceae	0.5	1	0.5	0.5	2	NG
Dalbergia sisso	Fabaceae	9	NG	4	NG	0.5	NG
Dendrocalamus hamiltonii	Poaceeae	NG	NG	1.5	1	2	NG
Peltophorum pterocarpum	Leguminosae	0.5	0.5	NG	0.5	NG	NG

B: Blank soil; M: Mycorrhiza inoculated; SMC: Soil with cow dung as manure; NG: Not Germinated

Table 3. Soil nutrients concentration in different phases of restoration and a comparison with earlier analysis by BCCL**.**

Soil Parameter	Soil analysis by BCCL (2012)	Analysis by TERI SAS			Analysis by other researchers (Chaulya et al. 2000)
		Pre-restoration	Restoration initiation	Post-restoration	
Bulk Density(g/cm^3)	NA	1.304	NA	NA	1.76
pH	4.5	7.8	5.45	6.90	7.52
Electrical conductivity(mmhos/cm)	0.164	1.92	NA	NA	NA
Organic Carbon (%)	NA	0.72	1.75	4.20	1.22
Nitrogen (kg/ha)	NA	68.45	167	449	89
Phosphorous (kg/ha)	NA	3.1	14.2	64.7	8.1
Potassium (kg/ha)	NA	NA	167	607	131.2
Sodium (kg/ha)	NA	NA	183	166	NA

NA: not available

Table 4. Heavy metals (Mean ±SD) in cow dung manure, leaf manure and in soil at different phases of restoration

Substrate	Heavy metals (ppm)				
	Cr	Cd	Pb	As	Ni
Manure					
Cow dung	1.21 ± 0.001	ND	2.18±1.021	ND	0.94 ± 0.001
Leaf	1.63 ± 1.314	ND	2.97 ± 0.981	ND	7.01 ± 0.921
Soil					
Pre-restoration phase	34.6	0.007	13.4	1.03	18.1
Restoration initiation phase	30.5 ± 2.12	0.012 ± 0.001	9.1 ± 0.663	1.02 ± 0.001	17.25 ± 0.937
Post-restoration phase	27.1 ± 2.14	0.003 ± 0.001	8.3± 0.719	1.05 ± 0.001	18.23 ± 0.306

ND: not detectable

Table 5. Values of selected water parameters at post plantation phase

Water parameters	WHO (1997)	Standard value (IS: 10500 Desirable Permissible Limit)	Observed values at post-plantation (Mean ± SD)	Observed values (Rai and Singh 2011)
pH	7.0–8.5	NA	7.32 ± 0.026	8.08
Electrical Conductivity (mS/m)	0.750	NA	1.83 ± 0.032	1.009
Alkalinity (mg/l)	NA	NA	6.00 ± 0.058	NA
Hardness (mg/l)	30	0.164	4.68 ± 0.058	50
Nitrate (mg/l)	50	NA	10.75 ± 0.054	1.56
Sulfate (mg/l)	200	4.5	8.7 ± 0.023	446

NA: not available

Table 6. Heavy metals in water samples from OB dump area

Heavy Metal (ppm)	Observed value at post restoration	Detection Limit	Observed values (Tewari et al. 2020)	ISO-14000 Standard Schedule (2012)
Chromium	0.0067	0.006	0.0002	2.0
Cadmium	ND	0.002	NA	2.0
Lead	0.0023	0.4	NA	0.1
Arsenic	ND	0.01	0.0003	0.2
Nickel	0.0016	0.1	0.0058	3.0

ND: not detectable, NA: data not available

Biodiversity indicators

The Shannon Weiner diversity index for restored soil was found as 2.0311 as compared to 1.4709 for non-restored soil. The similarity index between RS and NRS was 0.36, indicating low similarity between both the sites in terms of shared insect orders. The evenness index at RS was 0.681 and at NRS was 0.759 indicating that the numbers of individuals of present insect order at both sites were distributed slightly more evenly at NRS than in the restored land (Table 7).

There was an observable difference between both the sites, suggesting presence of a higher biodiversity of insects at RS than NRS. A total of 77 insects were analysed belonging to 11 taxonomic orders that were recorded in this study (Table 8).

These included Blattodea (Roaches), Coleoptera (Beetles), Dermaptera (Earwigs), Diptera (Flies and

Table 7. Diversity, similarity, evenness indices of insects at restored and non-restored sites

Insect Order	Number of individuals	
	Restored site	Non-restored site
Blattodea	2	1
Coleoptera	14	1
Dermaptera	2	0
Diptera	3	0
Hemiptera	11	0
Hymenoptera	15	1
Isoptera	1	0
Lepidoptera	9	0
Odonata	5	0
Orthoptera	8	3
Mantodea	0	1
SUM	**N = 70**	**N =7**
Simpson's diversity	6.8148	3.7950
Simpson's evenness	0.68148	0.759
Similarity index	0.36	
Shannon-wiener diversity index	2.0311	1.4709
Species evenness	0.8820	0.9139

Mosquitoes), Hemiptera (True bugs), Hymenoptera (Ants, Wasps and Bees), Isoptera (Termites), Lepidoptera (Butterfly and Moths), Odonata (Dragonflies and Damselflies), Orthoptera (Crickets and Grasshoppers) and Mantodea (Praying Mantis). In RS, a total of 70 insects were recorded in classified five different zones. In vegetable zone a total of 15 insects were recorded under 6 orders as 4 coleopterans, 1 dipteran, 2 hemipterans, 3 hymenopterans, 1 lepidopteran and 4 orthopterans. In medicinal zone only four insect orders were recorded, as 1 blattodea, 1 dermapteran, 2 hymenopterans and 1 orthopteran. At the wetland, 2 coleopterans, 1 hemipteran, 2 hymenopterans, 1 lepidopteran and a significant 4 odonata along with a single orthopteran were recorded. The plantation zone which was divided into two parts due to its large land cover recorded the highest insect diversity in both plantation zones one and two, i.e., a significantly higher number of 4 coleopterans, 7 hemipterans, 4 hymenopterans and 6 lepidopterans along with a single individual of dipteran, isopteran, odonata and orthopteran each in plantation zone one. Similarly, the highest biodiversity was also recorded at the

Table 8. Insect diversity according to various land use sections in study site

ORDERS	ZONES					
	Vegetable	Medicinal	Watershed	Plantation sampling site 1	Plantation sampling site 2	Non-Restored
Blattodea		+			+	+
Coleoptera	+ + + +		+ +	+ + + + +	+ + +	+
Dermaptera		+			+	
Diptera	+			+	+	
Hemiptera	+ +		+	+ + + + + +	+	
Hymenoptera	+ + +	+ +	+ +	+ + + +	+ + + +	+
Isoptera				+		
Lepidoptera	+		+	+ + + + + +	+	
Odonata			+ + + +	+		
Orthoptera	+ + + +	+	+	+	+	+ + +
Mantodea						+
SUM*	**6**	**4**	**6**	**8**	**8**	**5**

+ indicates individual insect, *represents in total how many types of insect Orders observed in a given zone

plantation zone second with 8 recorded taxonomic orders, comprising 3 coleopterans, 4 hymenopterans and one individual each under blattodea, diptera, dermaptera, hemiptera, lepidotera and orthoptera. For insect diversity in NRS, only 5 insect orders were recorded constituting 1 individual each under blattodea, coleoptera, hymenoptera, mantodea and 3 orthopterans, which overall had the lowest insect diversity only after medicinal zone, whereas the highest diversity was observed in plantation zone one in terms of both richness and abundance. All these orders are essential biological indicators and provide important ecosystem services of pollination and soil nutrient transfer (Lengyel et al. 2018, Buchori et al. 2018).

Plant growth response

The graphs (Fig. 2) compare six species of plants grown in restored coal mined soil. Ten individual plants were monitored without mycorrhizae and twenty with mycorrhizae treated soil.

The comparative analysis of each species shows a higher growth trend in mycorrhiza infused plants than control plants. This pattern is observed possibly due to rhizofiltration that is the removal of contaminants from flowing water/soil; this can be achieved by the plant itself or the microorganisms associated with the rhizosphere (Wong 2003). Similar results have been reported from Singrauli, India that confirms that unaided natural revegetation either legume or non-leguminous, are not as effective in mine spoil rehabilitation as compared to the plantation of native species (Singh and Singh 2006). In another study, plant growth patterns for ten plant species conducted at five permanent coal mine dumps (Mandaman, Chora, Mudidih, South Balanda and Ghugus) of India *viz*., *Dalbergia sisoo, Azadirachta indica, Albizia procera, Delonix regia*, *Acacia nilotica, Leucena leucocephala, Pithocelobium dulce, Pongamia pinnata, Casurina* spp. and *Prosopis juliflora*. The study concluded that the growth of *Dalbergia sissoo* found highest in terms of height, girth and biomass for all the regions. The high growth rates of *D. sisoo* concluded due to presence of root nodules with having nitrogen fixing bacteria. In the Katras region, Dhanbad *D. sisoo* and *L. leucocephala* were found to be fastest growing species (Chaulya et al. 2000). An averaged growth rate in the present study for 17 months inferred that *B. variegata* had highest and *S. robusta* had the least growth over time irrespective of the growth medium.

Except *S. robusta*, all planted species showed 80-100 percent survival rate. The survival rate for control was least in *S. robusta* and highest for *B. variegata* (Table 9). The limited experimentation within the initiative indicated that use of mycorrhizal inoculum and drip irrigation methods have increased the rate of survival and improved growth rate of the native species.

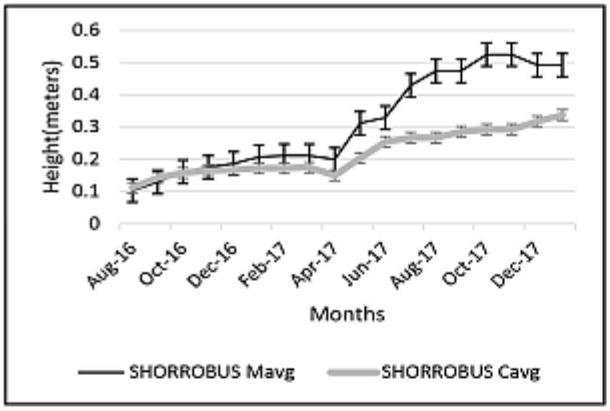
Microbial analysis

Microbial activity through Luria Bertini solid media plates showed appearance of colonies after 48 hours. A total of 5 pure colonies were isolated from the plates from degraded unrestored OB Dump (D), 6 pure colonies from restored soil without mycorrhiza (RC) and 6 pure colonies from restored soil with mycorrhiza (RM). Microbes present in degraded soil are surviving stressed conditions and may be useful for breaking down stressed conditions in other ecological niches as well. Similarly, microbes found in RC and RM although different than those found in D, may also have an additional role in enhancing growth of plants cultivated in these soils.

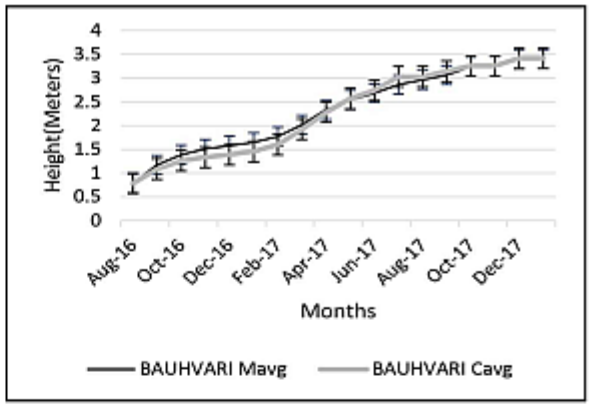
Although all samples showed microbial activity, however, the quantity (CFU, colony forming unit) was found to be decreased in the degraded soil sample followed by restored soil and increased in mycorrhiza treated restored soil. In terms of diversity, it is important to note that highest isolates (14) were obtained in RC, 6 in RM and lowest 4 in samples from degraded soil. Selective media results showed that RC had positive isolates for all, while RM had shown positive isolates only in Asparagine Nitrate Medium. Degraded soil sample tested positive for isolates in Actinomyces and Sulphate Reducing Agar. Nitrogen fixers as well as putative rhizobia were also observed in the restored sample. Higher CFU and diversity indicates possible existence of more favourable microenvironment in restored soil for microorganism's growth as compared to degraded soil.

CONCLUSIONS

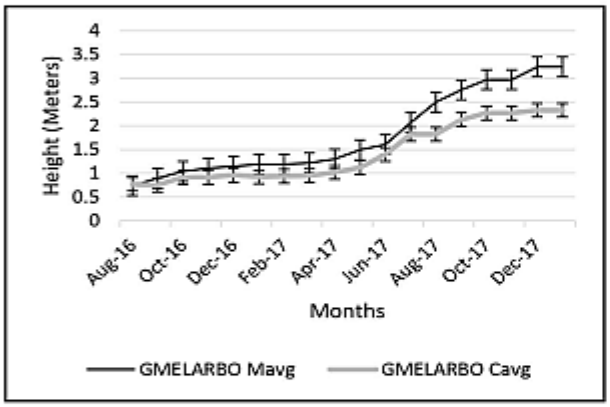
The study has been implimented by Doctoral and Masters level students at TERI School of Advanced Study, New Delhi. Learning Forest restoration has been a learning experience to the students. We understand that coal mining has caused noteworthy



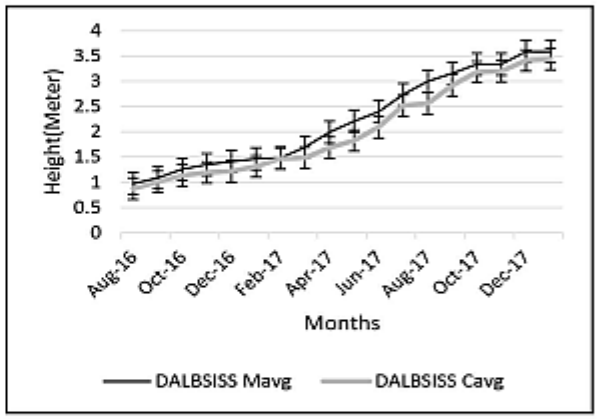
Graph 1: Growth patterns of *Shorea robusta*



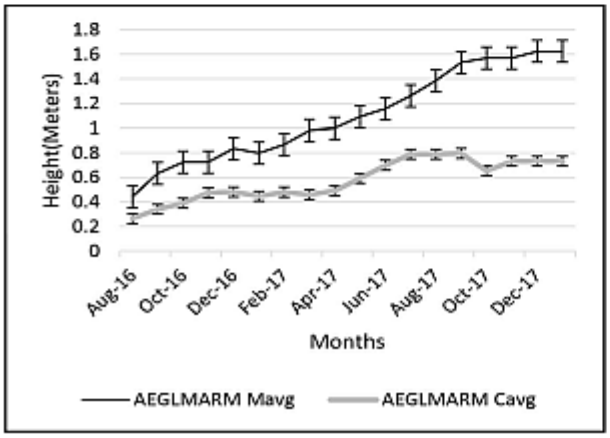
Graph 2: Growth patterns of *Bauhinia variegata*



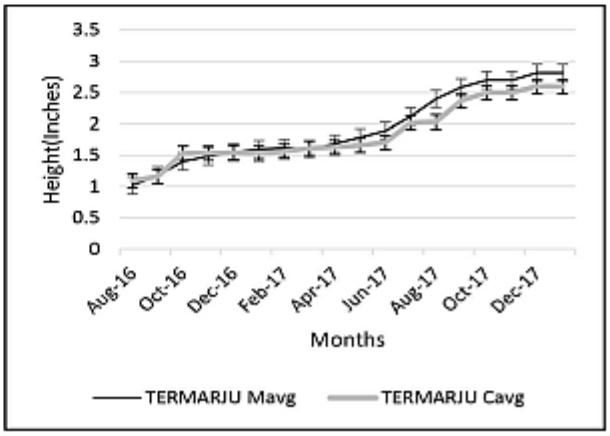
Graph 3: Growth patterns of *Gmelina arborea*



Graph 4: Growth patterns of *Dalbergia sisoo*



Graph 5: Growth patterns of *Aegle marmelos*



Graph 6: Growth patterns of *Terminalia arjuna*

Figure 2. Graphs 1-6, showing the growth of six tree species in plantation zones.

forest loss and has created mine wastelands which remain largely non-reclaimed (Malviya et al. 2010). In the last three decades Jharkhand state in the initial stage carried mining mostly in dense forest which today exist as open forest post reclamation. The 55.35% area of the dense forest in Jharkhand was converted to open forest and 1.85% area of open forest converted was reduced to degraded forest during the years 1992 to 2004. In the timespan of 2004 to 2009 the 7.68% area of dense forest was changed making a cumulative of 71.85% area of the total forest area in Jharkhand state (Kumar and

Table 9. Percent survival of tree species planted in study site

Species	Family	No of individuals sampled	Percent Survival
Aegle marmelos (M)	Rutaceae	20	100
Aegle marmelos (C)	Rutaceae	10	80
Bauhinia variegata (M)	Legumes	20	100
Bauhinia variegata(C)	Legumes	10	100
Dalbergia sissoo (M)	Legumes	20	100
Dalbergia sissoo (C)	Legumes	10	100
Gmelina arborea (M)	Verbenaceae	20	100
Gmelina arborea (C)	Verbenaceae	10	90
Terminalia arjuna (M)	Combretaceae	20	100
Terminalia arjuna(C)	Combretaceae	10	90
Shorea robusta (M)	Dipterocarpaceae	20	65
Shorea robusta (C)	Dipterocarpaceae	10	50

M: Mycorrhizal inoculum-based plantation; C: Control

Pandey 2013). The degradation of land leads to fragmentation of landscapes ecosystem services. It is evident that forest restoration should not be observed as final reclamation but a progress towards continuous improvement of techniques and interventions. This approach of measuring the ecosystem services provides externalities of benefits to the society. The restoration processes need to develop towards multiple societal demands for ecosystem services. The mining agencies should improve restoration practices and ensure continuous scientific studies for the intended outcomes. Mine OB reclamation should focus on integration of best reclamation practices that increase the direct and indirect ecosystem services of the land. India requires permanent monitoring plots (PMPs) for understanding the relationship between forest reclamation process and wilderness. A network of restored PMPs at different stages of succession can unleash knowledge on the science of restoration.

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Table S1. List of plant species planted in different zones at the project site

Zone	Plant Species
Plantation with forest trees	*Dalbergia sissoo, Shorea robusta, Aegle marmelos, Terminalia arjuna, Gmelina arborea, Bauhinia variegata*
Fruit bearing trees	*Psidium guajava* (Guava), *Syzygium cumini* (Jamun), *Annona squamosa* (Shareefa), *Tamarindus indica* (Imli)
Vegetables	*Allium cepa* (Onion), *Allium sativum* (Garlic), *Brassica oleracea var. botrytis* (Cauliflower), *Coriandrum sativum* (Coriander), *Phaseolus vulgaris* (Common Bean), *Raphanus sativus var. Longipinnatus* (Radish), *Solanum melongena* (Eggplant), *Solanum tuberosum* (Potato), *Spinacia oleracea* (Spinach)
Medicinal plants	*Cymbopogon flexuosus* (Malabar Grass), *Bryophyllum pinnatum* (Pathar chur), *Ocimum tenuiflorum* (Tulsi), *Chrysopogon zizanioides* (Khas Khas), *Aloe vera, Phyllanthus emblica* (Amla)
Wetland	No plantation activities done

Table S2. List of species considered for germination test

Species	Family	Pre-sowing treatment
Acacia catechu	Leguminosae	Cold water treatment for 24 hours.
Acacia catechu variety	Leguminosae	Cold water treatment for 24 hours.
Aegle marmelos	Rutaceae	No pre-sowing treatment.
Ailanthus excelsa	Simaroubaceae	10 minutes soaking in hot water (60° C).
Albizia odoratissima	Fabaceae	20-25 minutes soaking in H_2SO_4.
Annona squamosa	Annonaceae	40 minutes soaking in H_2SO_4.
Aegle marmelos	Rutaceae	No pre-sowing treatment.
Bauhinia purpurea	Leguminosae	2-3 minutes hot water treatment followed by 10 minutes of cold water treatment.
Ceiba pentandra	Malvaceae	24 hours soaking in cold water.
Dalbergia sissoo	Fabaceae	Seeds were soaked in cold water for 2 hours.
Dendrocalamus calostachyus	Poaceeae	Scarification.
Dendrocalamus hamiltonii	Poaceeae	Scarification.
Dendrocalamus strictus	Poaceeae	Scarification.
Emblica officinalis	Euphorbiaceae	Seeds were soaked into cold water for 24 hours.
Gmelia arborea	Lamiacea	10 minutes soaking in H_2SO_4.
Haldina cordifolia	Rubiaceae	2 hours soaking in hot water.
Peltophorum pterocarpum	Leguminosae	Seeds were soaked in boiling water for 2 minutes followed by overnight soaking in cold water.
Psidium guajava	Myrtaceae	Soaked in water for 24 hours followed by 3-5 minutes soaking in HCl.
Swietenia mahagoni	Meliaceae	No treatment.