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Recovery of Ecosystem Functions on a Restored
Limestone Mine area in the Foothills of Himalaya

The study aims at assessing various ecosystem functions of a limestone mine area, restored 30 years back, in comparison to its adjoining natural forest. Both the areas have similar type of species composition. The natural forest is dominated by broadleaf species (Bauhinia semla, Sapium insigne) whereas, the restored area has Boehmeria rugulosa, Cupressus torulosa, Bauhinia semla as the dominant tree species. Though the number of species of various life forms (trees, shrubs, herbs, and grasses) was low in the adjoining natural forest, the estimated total basal cover (TBC) was much higher (2497.65 cm²/100 m²) compared to the restored area (674.64 cm²/100m²). Higher diversity was recorded in the restored mine area which reflects the ability of the system to provide stable forest functions, especially in the global climate change scenarios. Microbial activity in the top soil layer was found to have increased substantially in the restored mine site. Annual litter production, soil respiration rate, and soil microbial biomass in the restored mine area were comparable with that of the natural forest. It indicates a significant level of organic matter and detritus availability in the top soils of the restored area since degradable organic carbon present in the soil is the main fuel responsible for the CO_2 emission during soil respiration. Though the carbon assimilation rate recorded in the vegetation of the restored area is higher than that of vegetation of natural forest at the species level, at the community level, the restored area may have lower assimilation owing to lower TBC.

Key words: Limestone mine, Restoration, Soil respiration, Microbial biomass, Litterfall, Ecosystem function.

Various ecosystem functions of a mine degraded land have taken its recovery trajectory close to the adjoining natural forest following restoration efforts which have improved ecosystem functions of mine degraded land.

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Introduction

Areas under surface mining create vast stretches of devastated lands which are technically speaking areas of 'no value' or to be more precise of 'negative value'. This means that whereas the area after mining has, on one hand, lost its ecological and socioeconomic yield capability, on the other hand, it is a threat to the ecological and socio-economical stability. Most of this mining happens to occur in forested areas and once the mining operation starts forests suffer enormously. Several efforts have been made in the past to restore or reclaim mine overburden areas of different types through establishing experimental plots and raising plantation of different species. Some of them have yielded excellent results during the initial stage. However, true and meaningful assessment of their effectiveness usually remains unaddressed because of limitations of project duration. Since such restoration work involves plantation of a combination of suitable tree, shrub, herb, and grass species the benefit accrued out of the restored area in terms of carbon regulating services, soil health and other elements of livelihood to the local people require a substantial time to be visible.

Limestone mining was rampant in Doon valley and Mussoorie hills till the early eighties with 105 working mines in the region (Rajdeep *et al.*, 2011). Ecological restoration of these mined areas in the Doon-Mussoorie region started almost three decades back by various agencies, including the state forest department (ibid). One such site where restoration work was done by UP State Mineral Development Corporation (UPSMDC) from 1988 to 1989 is Chunakhala limestone mine area in

Dehradun District of Uttarakhand. An assessment of the floristic composition and species diversity was done (Rajdeep *et al*., 2011) which indicated that the primary colonizing species are thriving successfully on the earlier derelict site. However, the carbon regulating services such as carbon assimilation, soil respiration, soil microbial biomass carbon and leaflitter nutrients in the restored area remained unassessed.

Primarily, evaluation of restoration success on surface mined lands is based on surface topography reconstruction, characteristics of the re-established plant community, and soil erosion protection (Stahl *et al*., 2006). Restoration of ecosystem functions such as nutrient cycling, organic matter decomposition, soil development, and community dynamics are not directly examined but are assumed to be recovering to the degree that the system will be self sustaining and resilient to environmental stress (ivid). We attempted to assess the success of mine land restoration work in terms of improving various ecosystem functions and carbon regulating services in the limestone mine area of Chunakhala. The restoration work is now over 30 years old and expected to be ecologically more stable generating various tangible and intangible benefits.

Material and Methods

Study area

The study was conducted in the restored mine site (approx. 4 ha) of Chunakhala and the adjoining natural forest situated in the foothills of the Himalaya (Fig. 1). 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 1386 to 1419 m AMSL. Geographic coordinate of the site is 30°25′49.1″N latitude and 78°04′32″ E longitude. The natural forests of Chunakhala fall in the subtropical forest zone which are monsoon forests that are characterized by being leafless during the latter part of winter and hot dry spring (Rajdeep *et al*., 2011). The government initiated restoration of the heavily degraded mining site in 1988-1989 (GoU, 2021).

Vegetation

Vegetation survey was carried out by quadrat sampling method following Misra (1968). Ten quadrats of 10×10 m^2 size for trees, 10 plots of 3×3 m^2 for shrubs, and 10 plots of 1×1 m^2 for herbs were laid out in the restored area of Chunakhala mined area and in the natural forests adjoining the restored site. The diameter at breast height (DBH at 1.37 m above the ground) of all individual trees in each quadrat was recorded. For shrubs and herbaceous vegetation, species and their number of individuals and collar diameter were recorded. The vegetation of both sites was analyzed for frequency, density, and abundance following Curtis and McIntosh (1950). The relative values were determined as per Phillips (1959). These values were summed to

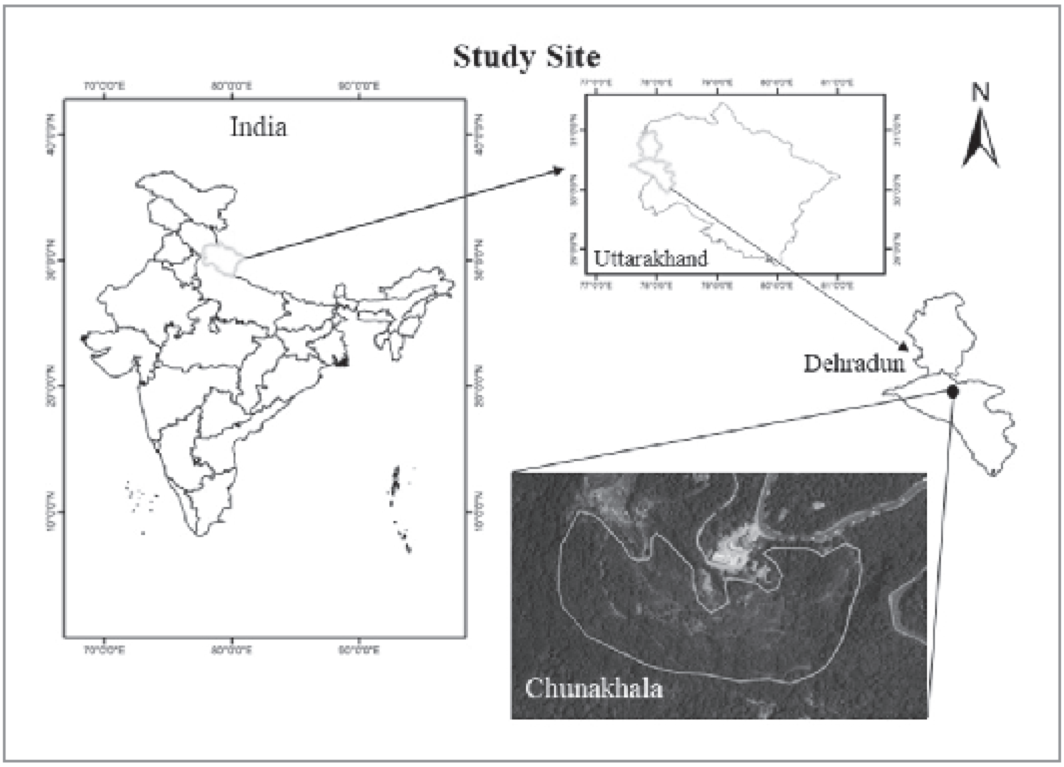

Fig. 1: Chunakhala study area on Dehradun-Mussoorie highway (Map downloaded from https://onlinemaps.surveyofindia.gov.in)

represent individual species' Importance Value Index (IVI) (Curtis, 1959). Shannon and Wiener diversity index (H) was calculated using the formula given below (Shannon and Wiener, 1963).

Shannon Index of diversity (H) = $-\sum_{i=1}^{s} p_i \ln p_i$

Where p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of the calculations, and s is the number of species.

Litterfall production

Litterfall estimation was carried out by litter plots using the standard ground sampling method. Ten permanent litter plots each of size 1x1m were laid out in the restored site and in the adjacent natural forest. All the litter plots were initially cleared. Monthly litterfall was collected and weighed to obtain the fresh weight and samples were brought to the laboratory for oven-dry weight estimation at 60 to 70 ^{0}C till the constant weight for estimation of litter production. The decomposition constant (k) was calculated using the model of Olson (1963):

$$X/Xo = e^{-kt}$$

Where, Xo = initial weight of the litter in the litter bag (g); X = the weight of litter remaining in the litter bag at time period t; k is the decay constant; t is time period (here 1 year) and e = the base of natural log.

This exponential model also allows the calculation of the half time (0.693/k) or time required to reach 95% loss (3/k).

Carbon assimilation

Dominant species (based on IVI) of the restored mined area and the adjoining forest area were selected for recording carbon assimilation rate. The canopy of the chosen tree was stratified into three strata *i.e.* top, bottom, and middle. Each stratum was divided into four directions making twelve sampling points in a tree. The carbon assimilation rate (μmol CO_2 $m^{-2}s^{-1}$ was investigated using a portable photosynthesis analyzer (LI-COR-6400 XT, Lincoln, NE) in healthy and fully expanded leaves between 09:30 a.m. to 01:30 p.m. in clear sky conditions.

Soil respiration

The Soil respiration was measured from 10 places each in the restored mined area and the adjoining forest area using a portable trace gas analyzer (Licor portable smart chamber 8200-01).

Soil microbial biomass carbon (MBC)

Microbial biomass carbon in 0-15 cm soil layer was estimated following chloroform fumigation extraction procedure as described by Jenkinson and Powlson (1976) and modified by Vance *et al.* (1987). It was calculated from the relationship $Bc = Fc/Kc$ where Fc is the difference between extractable carbon from fumigated soil and non-fumigated soil. Kc is the conversion factor, which is 0.45 (Vance *et al*., 1987).

Litter nutrients

Nitrogen was analyzed by Macro Kjeldahl method (Loomis and Shull, 1937). Carbon (C) estimation was made using Elementar make CNS analyzer; whereas potassium (K), calcium (Ca) and magnesium (Mg) were analyzed by tri acid method (Jackson, 1973) making appropriate dilution of stock solution and taking readings in Flame Photometer after placing the respective filters. Phosphorus (P) was estimated using spectrophotometer following the tri acid digestion method (Jackson, 1973).

Results and Discussion

The work is based on a detailed survey, collection of data on various vegetation parameters, litterfall production, litter decomposition, litter nutrient dynamics, carbon assimilation, soil respiration and soil microbial biomass.

Vegetation

Vegetation of the restored mine area and the adjacent natural forest area was studied following standard methodology (Misra, 1968) to find out the variation in the number of species of different life forms and the total basal area of trees and shrubs. Species dominance in the study areas was determined using Importance Value Index (IVI). Identification of vegetation in the field was made with the help of respective research papers (Joshi *et al*., 2013 and Rajdeep *et al*., 2011), floras (Gaur, 1999; Naithani, 1990; Raizada and Saxena, 1977) of the region. *Bauhinia semla* was the most dominant among the tree species recorded from the natural forest area with an IVI of 162.94. The next dominant tree species was *Sapium insigne* with IVI of 34.85 followed by *Celtis tetrandra* (23.23), *Boehmeria rugulosa* (20.13), *Machilus odoratissima* (15.00) and *Syzygium cumini* (14.08), *Cassia siamea* (9.88) and *Grewia optiva* (9.83). *Debregeasia saeneb* and *Murraya koenigii* were the dominant shrub species with an IVI of 67.50 and 17.54, respectively. *Eupatorium adenophorum* and *Acyranthus aspara* were most abundant herb species in natural forest area. In the restored mine site the most dominant tree species was *Boehmeria rugulosa* with an IVI of 53.90 followed by *Cupressus torulosa* (51.10), *Bauhinia semla* (39.87), *Toona ciliata* (26.04), and *Sapium insigne* (22.32). All other tree species had IVI value less than ten. *Coriaria nepalensis* is the dominant shrub in restored mined area with IVI of 41.60. The herbaceous layer is dominated by *Chrysopogon* sp. and *Apluda mutica*.

The Shannon and Wiener diversity index (Table 1) suggests that the restored mined area displayed higher diversity with respect to all the life forms compared to the adjoining natural forest. The difference is more prominent in tree species which may be attributed to restoration efforts where a large number of species was introduced in the area. Higher diversity in the restored mine area reflects the ability of the system to provide stable forest functions (Aerts and Honnay, 2011), especially in the global climate change scenarios, which predict more frequent extreme disturbances and climatic events.

The number of species of various life forms was higher in the restored mine area compared to the adjoining natural forest (Table 1). Despite having less number of species of different plant forms total basal cover (TBC) estimated for the natural forest was much higher (Table 2) compared to the restored area. The difference is much higher in TBC of trees compared to shrubs.

It was observed that the restored sites and the adjoining natural forest have a similar type of species composition. The natural forest is dominated by broadleaf species (*Bauhinia semla, Sapium insigne*) whereas, the restored area has *Boehmeria rugulosa*, *Cupressus torulosa*, *Bauhinia semla* as the dominant species. However, the total basal cover is much higher in the natural forest compared to the restored sites. This difference in structure of different species might have a significant impact on the overall ecosystem functions and carbon regulating services in the study area.

Litterfall production

Monthly litterfall (Kg ha^{-1}) at restored mine site and adjoining natural forest is shown in Figure 1. No significant difference in the annual litter production was observed between the two sites though it was marginally higher in the restored mine area (5020.25 kg $ha^{-1}y^{-1}$) compared to the adjoining natural forest (4999.78 kg $ha^{-1}y^{-1}$). The annual litter production observed in the present study compares well with the other reported studies (Ahirwal *et al*., 2021; An *et al*., 2017). We observed a multimodal pattern of litterfall where one peak was observed in the month of January (winter) and the others in May (the dry season) and August. The seasonal patterns of litterfall inputs are generally unimodal, bimodal, multimodal, and irregular depending on the species and sampling month. In temperate forests, the seasonal dynamics of broad-leaved stands show a unimodal peak in autumn, whereas coniferous stands show multimodal peaks (Zhang *et al*., 2014). Global study also suggests that for tropical forests, the litter peaks were found mostly in spring or winter, corresponding to the drought season (Zhang *et al*., 2014). The litter peaks of tropical forests are not usually concentrated in a short time, and the intensity of seasonal variability is relatively weak (ivid.), as has been observed in the present study (Fig. 2). Shrubs generally produce more foliage, which in turn is responsible for producing more organic matter (Joshi *et al*., 2013). The litter production could be mainly attributed to species composition, climatic conditions, and their dominance (Joshi *et al*., 2013). Within the same climate range tree species composition was important for litter production (Sundarapandian and Swamy, 1999).

Leaf litter nutrients

Seasonal variation in major nutrient and carbon content in leaf litter collected from Chunakhala restored sites and adjoining natural forest area has been analysed and presented in Table 3. The data obtained were subjected to analysis of variance (ANOA). The percent N, P, Ca, and Mg were significantly ($p<0.001$) low in the summer months compared to the Spring, Monsoon, and Winter months whereas, potassium (K) content in the leaf litter was significantly ($p< 0.001$) high in the summer months. This may be attributed to high resorption proficiency in the summer months, consistent with the sink-source hypothesis. According to this hypothesis, we might expect resorption to be positively correlated with plant growth rates (Lusk *et al*., 2003). Dynamics in the major cation K may suggest that leaching from leaf tissue in the canopy is an important source of variation in this nutrient. Pande (2001) also reported high concentration of N in leaf litter of *Shorea robusta* Gaertn. plantation at Doon valley during September, December and low concentration in May.

Table 1 : Number of species of different plant forms and their diversity index (H) in restored mine area and adjoining natural forest

Plant form	Restored mined area		Natural forest	
	Number	Diversity index (H)	Number	Diversity index (H)
Tree	14	2.35	11	1.68
Shrub	24	2.55	14	2.05
Herbs and grasses	30	2.81	17	2.26
Total	68	-	42	-

Table 2 : Total basal cover (cm^2/100 m^2) in restored mine area and adjoining natural forest

Plant form	Restored mined area	Natural forest
Tree	445.60	2217.30
Shrub	229.04	280.35
Total	674.64	2497.65

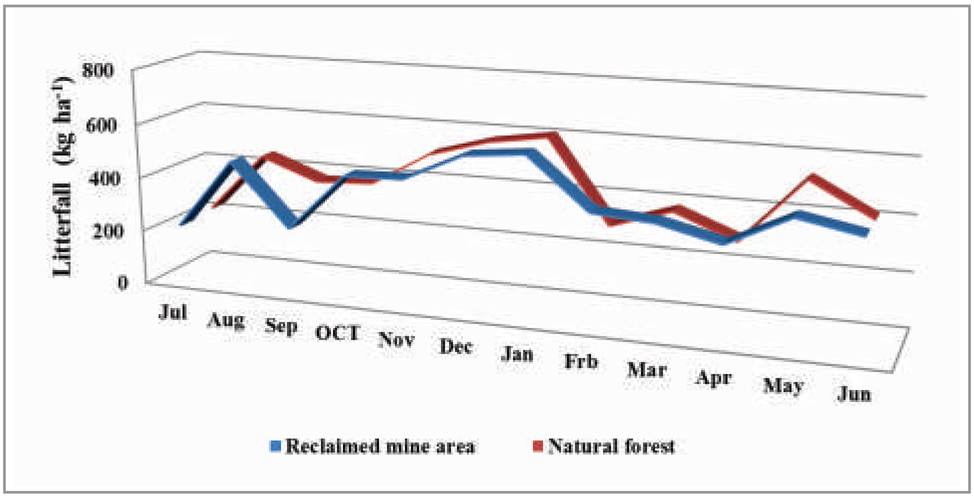

Fig. 2: Monthly litterfall in different sites (kg ha^{-1})

No significant variation was observed with respect to different nutrients and C:N ratio of litter samples in the restored mine area compared to the adjoining natural forest. However, the C:N ration was significantly high in spring and summer seasons compared to monsoon and winter season (Table 3).

Soil respiration

Soil respiration refers to the production of carbon dioxide when soil organisms respire. This includes respiration of plant roots, the rhizosphere, microbes and mycorrhizal associations. In the present study, we observed that the soil respiration rate in the restored mine sites is on a par (p=0.2113) with that of natural forest (Table 4). It indicates a significant level of organic matter and detritus availability in the top soils of the restored site. Degradable organic carbon present in the soil is the main fuel responsible for the CO_2 emission during soil respiration (Das *et al*., 2017). Soil respiration rates vary significantly among major plant biomes, suggesting that vegetation type influences the rate of soil respiration (Raich and Tufekcioglu, 2000) by influencing soil microclimate, quantity and quality of detritus supplied to the soil and root respiration. Factors such as temperature, moisture availability, and substrate properties that simultaneously influence the production and consumption of organic matter are more important in controlling the overall rate of soil respiration than is vegetation type in most cases (ivid). In general, soil moisture and soil temperature have been reported to influence soil respiration; however, vapour pressure and relative humidity also emerged as additional scientific variables affecting soil CO_2 emission with significant positive correlations (Sivaranjani and Panwar, 2021).

Soil microbial biomass carbon (MBC)

Soil microbial biomass carbon generally comprises some l-3% of total soil organic carbon, unless large quantities of substrate have recently been added or if the carbon content of the soil was very far from equilibrium when sampled (Jenkinson and Ladd, 1981). Soil samples from the top 15 cm soil layer were collected and

Table 3 : Seasonal variation in organic carbon and major nutrients (%) in litter samples.

Sites	Spring (February, March, April)							Summer (May, June, July)						
	C	N	K	Ca	P	Mg	C:N	C	N	K	Ca	P	Mg	C:N
Restored	46.51 ±0.21	1.09 ±0.28	0.16 ±0.04	1.08 ±0.02	0.24 ±0.16	0.48 ±0.14	42.67	46.6 ±0.06	0.76 ±0.52	1.74 ±0.08	0.73 ±0.13	0.05 ±0.03	0.09 ±0.03	60.41
Natural	46.59 ±0.16	1.01 ±0.18	0.17 ±0.03	1.09 ±0.02	0.38 ±0.15	0.56 ±0.14	46.12	45.19 ±12.12	0.93 ±0.11	1.6 ±0.07	0.69 ±0.10	0.03 ±0.01	0.12 ±0.01	33.97
Sites	**Monsoon** (August, September, October)							**Winter** (November, December, January)						
	C	N	K	Ca	P	Mg	C:N	C	N	K	Ca	P	Mg	C:N
Restored	43.62 ±1.45	1.36 ±0.22	0.71 ±0.14	1.41 ±0.44	0.21 ±0.17	0.57 ±0.04	32.07	43.10 ±1.23	1.32 ±0.2	0.23 ±0.06	1.17 ±0.16	0.41 ±0.13	0.58 ±0.15	32.65
Natural	42.40 ±0.87	1.49 ±0.46	0.62 ±0.15	1.37 ±0.35	0.20 ±0.11	0.61 ±0.06	28.45	43.68 ±0.87	1.16 ±0.20	0.17 ±0.04	1.11 ±0.05	0.45 ±0.27	0.52 ±0.16	37.65

Table 4 : Soil organic carbon (SOC), microbial biomass carbon (MBC) and soil respiration in different sites

Location	SOC (Mg ha^{-1})	MBC (mg g^{-1})	Soil respiration (mol m^{-2} s^{-1})
Restored mined area	14.91±8.30	0.18±0.08	9.75 ± 0.27
Natural forest	21.51±10.66	0.13±0.10	8.61 ± 0.20

Value of each parameter is the mean of 10 data

Table 5 : The decay constant (k) and time required for 50% and 95% loss of litter mass

Site	Xt/X	k	50%	95%
Restored mine area	0.59	0.51	1.34	5.80
Natural forest	0.57	0.55	1.26	5.45

analysed for soil microbial biomass carbon (Table 4). It was observed that microbial activity in the top soil layer has increased substantially given the fact that the plantation was done on an extremely degraded limestone mined area having large boulders and loose rock fragments that are devoid of moisture and nutrients. Soil MBC of the restored mine area is marginally lower than the MBC of natural forest with no significant difference (p=0.37223). Soil microbial Biomass is considered widely as the index of soil fertility and ecosystem productivity (Singh and Gupta, 2018). The soil stresses due to land degradation caused by mining activities are directly correlated with loss of microbial diversity and abundance or biomass dynamics. Addition of litter has been found to stimulate microbial growth and increase microbial biomass carbon (Mei *et al*., 2022).

Litter decomposition

Litter decomposition constitutes a valuable ecosystem service by recycling nutrients, and transferring energy in terrestrial ecosystems (Li *et al*., 2020) which replenishes pools of essential mineral nutrients, especially nitrogen and phosphorus, for net primary production (Abelho, 2016). The decay constant (k) estimated for the adjoining natural forest was higher compared to the restored mine area with less time required for 50% and 95% loss of litter mass (Table 5). The estimated time required for 50% weight reduction of litter in the restored mine area and the adjoining natural forest was 1.34 and 1.26 years, respectively. The result suggests that the restored mine area is in the process of restoring its carbon regulating services which compare well with the adjoining natural forest. It also points to favourable environmental conditions and decomposer community composition that is developing in the restored mine area that regulate litter decomposition in terrestrial ecosystems.

Comparable microbial biomass carbon (Table 4), soil respiration (Table 4) and C:N ratio (Table 3) estimated for the two sites also substantiate the finding. The litter quality, dominated by C:N ratio, has been found to explain the variation in litter decomposition (Li *et al*.,

Table 6 : Carbon assimilation rate (μmol CO_2 m^{-2} s^{-1}) of different species in restored mine area and natural forest.

Species	Habit	Restored mine area Average	Natural forest Average
Bauhinia semla	Tree	3.24	4.90
Boehmeria rugulosa	Tree	8.19	8.35
Cupressus torulosa	Tree	1.70	-
Sapium insigne	Tree	12.59	7.18
Machilus odoratissima	Tree	-	7.11
Toona ciliata	Tree	4.19	-
Phanera vahlii	Woody climber	5.30	-
Berberis lycium	Shrub	2.64	5.50
Coriaria nepalensis	Shrub	13.20	-
Colebrookea oppositifolia	Shrub	13.68	
Debregeasia saeneb	Shrub	12.77	2.13
Lantana camara	Shrub	23.21	
Lepidagathis sp.	Shrub	4.20	-
Murraya koenigii	Shrub	9.01	3.60
Urtica dioica	Shrub	8.8	12.50
Buddleja paniculata	Shrub	17.46	15.05
Saccharum spontaneum	Grass	3.49	-

'-' indicate absence

2020). The decomposition rate observed in the study compares well with the available literature on similar forests. Many researchers (Ahirwal *et al*., 2021) have estimated the decomposition constant, which shows high values in tropical forests in comparison to cool temperate and boreal forests. Swift *et al*. (1979) have reported the value of k as 0.21, 0.77, and 6.0 for boreal, temperate deciduous and tropical forests, respectively.

Carbon assimilation

The average carbon assimilation rate of the vegetation of the restored mine area of Chunakhala was 2.64 to 23.21 with an average of 8.99 µmol CO_2 m^{-2} s^{-1}. Whereas, the carbon assimilation rate varied between 2.13 to 15.05 µmol CO_2 m^{-2} s^{-1}, with an average value of 7.37 CO_2 m^{-2} s^{-1} for the vegetation in adjoining natural forest (Table 6). *Bauhinia semla*, the most dominant species in the natural forest displayed a lower average carbon assimilation rate (Table 6) compared to the dominant species (*Boehmeria rugulosa*) of the restored mine area. The overall carbon assimilation rate recorded in the vegetation of the restored area (8.99 µmol CO_2 m^{-2} s^{-1}) was higher compared to that of vegetation of the natural forest (7.37 µmol CO_2 m^{-2} s^{-1}). Previous study (Kumar *et al*., 2021) revealed that photosynthesis rate is positively correlated to the soil carbon stock. The lower average carbon assimilation rate in the natural forest, despite higher carbon stock, may be attributed to high density of the vegetation affecting photosynthetically active radiation (PAR) available for shrubs. Reduced availability of solar radiation due to cloudiness has been observed to cause a decline in the rate of photosynthesis (Singh *et al*., 2016).

Though the carbon assimilation rate recorded in the vegetation of the restored areas is on a par with that of vegetation of natural forest at the species level, at the community level the restored site may have lower assimilation owing to lower TBC (Table 2).

Conclusion

It was observed that the restored area and the adjoining natural forest have a similar type of species composition. The natural forest is dominated by broadleaf species (*Bauhunia semla, Sapium insigne*) whereas, the restored area has *Bhomeria rugulosa* and *Cupressus torulosa* as the dominant species. Though, the number of species of various life forms (trees, shrubs, herbs and grasses) was low in the adjoining natural forest, the estimated total basal cover (TBC) was much higher (2497.65 cm^2 /100 m^2) compared to the restored area (674.64 cm^2 /100 m^2). Though the carbon assimilation rate recorded in the vegetation of the restored areas is higher than that of vegetation of natural forest at the species level, at the community level, the restored area may have lower assimilation owing to lower TBC. Comparable litterfall production, litter nutrients, decomposition rate, microbial biomass carbon, soil respiration, C:N ratio and carbon assimilation estimated for the two sites points towards a favourable environmental conditions and decomposer community composition that is developing in the restored mine area that regulate litter decomposition in terrestrial ecosystems. Higher diversity in the restored mine area reflects the ability of the system to provide stable forest functions, especially in the global climate change scenarios, which predict more frequent extreme disturbances and climatic events. Our results contribute to the advanced understanding of various ecosystem functions and carbon regulating services in the restored limestone mine area and suggest that various ecosystem functions of the mine degraded land at Chunakhala have taken their recovery trajectory close to the adjoining natural forest following restoration efforts.

हिमालय की तलहटी में पुनर्स्थापित चूना पत्थर खदान व आस-पास के प्राकृतिक वन क्षेत्र के पारिस्थितिकी तंत्र कार्यों का तुलनात्मक अध्ययन

एन.बाला, विजेन्द्र पाल पंवार, संतोष नौटियाल, आशीष कुमार, तारा चन्द और पी.के. वर्मा

सारांश

वर्तमान अध्ययन में 30 साल पहले पुनर्स्थापित किए गए चूना पत्थर खदान क्षेत्र और इसके आस-पास के प्राकृतिक वन के विभिन्न पारिस्थितिकी तंत्र कार्यों का आंकलन और तुलना की गई। वर्तमान में दोनों क्षेत्रों में समरूप प्रजातियों की संरचना है। प्राकृतिक वन में *बाउहिनिया सेमला, सैपियम इनसिग्नी* का वर्चस्व है, जबकि पुनर्स्थापित क्षेत्र में *बोहेमेरिया रगुलोसा, कुप्रेसस टोरूलोसा, बाउहिनिया सेमला* प्रमुख वृक्ष प्रजातियां है। आस-पास के प्राकृतिक जंगल में विभिन्न वनस्पति (पेड़, झाडियां, जडी-बूटियां और घास) की प्रजातियों की संख्या कम होने के उपरांत भी, आंकलित कुल बेसल कवर (TBC) पुनर्स्थापित क्षेत्र (674.64 वर्ग सेमी /100 वर्ग मीटर) की तुलना में बहुत अधिक (2497.65 वर्ग सेमी/ 100 वर्ग मीटर) दर्ज किया गया है। अध्ययन में पुनर्स्थापित खदान क्षेत्र में उच्च विविधता दर्ज की गई जो विशेष रूप से वैश्विक जलवायु परिवर्तन परिदृश्यों में स्थिर वन कार्यों को प्रदान करने की क्षमता को दर्शाती है। पुनर्स्थापित खदान स्थलों की गतिविधियों में बढ़ोतरी पाई गई है। खदान क्षेत्र में वार्षिक करकट उत्पादन, मृदा श्वसन दर और मृदा माइक्रोबियल बायोमास प्राकृतिक वन के साथ तुलनीय है। मृदा में कार्बनिक पदार्थ और अपरद की उपलब्धता इस पुनर्स्थापित क्षेत्र के एक महत्वपूर्ण स्तर को इंगित करता है क्योंकि मृदा में मौजूद अवक्रमणीय जैविक कार्बन, मृदा श्वसन प्रक्रिया के दौरान CO_2 उत्सर्जन के लिए जिम्मेदार मुख्य ईंधन है। हालांकि पुनर्स्थापित क्षेत्रों की वनस्पतियों में दर्ज की गई कार्बन स्वांगीकरण दर, प्रजाति स्तर पर प्राकृतिक वन की वनस्पति की तुलना में अधिक है, परन्तु सामुदायिक स्तर पर कम टीबीसी के कारण पुनर्स्थापित क्षेत्र में कम स्वांगीकरण हो सकता है।

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