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Research

Functions of microarthropods in reclaimed mines spoil: A case study of Kathara Coalfield area of Jharkhand, India

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Abstract
Reclaimed mines spoil (RMS) is the byproduct of open-cast mining and an ecological footprint under twin stresses namely, anthropogenic and natural. The present paper measures the stresses in reclaimed coal mine spoils and has two sections – the first dealing with the experiments and their results, while the second section derives an ecological model from the experiment. An experiment was carried out (experimental years, 2006 – 2008) in reclaimed coal mine spoils (RMS) of Jharkhand. Four RMSs of different chrono sequences of plantations on the overburden dumps (OBD) were considered for the study. Data on soil arthropods along with other physical parameters were collected from a 1meter x 1meter grid of quadrate periodically. It was observed that the Shannon diversity index of younger RMS was higher than the 15- and 30-year-old RMS. Old age sites and forests had a higher Diversity Index. Simpson's index was 0.0877, 0.889, 0.869, and 0.887 in four RMS sites, and 0.885, and 0.917 in the forest. Organisms in degraded systems are initially rudrals – create a functional system and establish as K-select species. It was observed that the system has stresses – homeostatic processes that keep a system in its original state, and other forces – resilience pulls them out of the *status quo* but in reclaimed mine spoils an additional force anthropogenic activities work synergistically with the forces of resilience that push the system towards non-equilibrium, which is critical for succession and ecesis. Based on findings and functional stresses in the system an ecological model was developed for ecesis that is operative in the system.

Keywords: Homeostasis, resilience, ecological stress, anthropogenic activities; ecesis soil-arthropods, ecological model

Introduction

Human development processes, over time, have reduced the capacity of ecosystems to cope with the combination of top-down and bottom-up anthropogenic interventions. The impact, scars on the face of the earth, habitat loss, degradation and derelict ecosystems. The main concern for the managers of the biological systems is to contain the increasing ecological footprints on the globe, which has become a monster, annihilating mankind. Therefore, it is pertinent to address problems objectively – first to halt habitat loss so that the total area under derelict or degraded ecosystems does not increase, and secondly, to take measures to revert the derelict ecosystems so that there is restoration and establishment of both functional-group diversity and functional-response diversity (Folke, et al., 2004) to generate ecosystem services (Chapin *et al*. 1997, Luck *et al*. 2003).

Ecosystems are complex, adaptive systems that are characterized by historical dependency, and nonlinear dynamics and are never in equilibrium (Levin, 1999). The likelihood that an ecological system will remain within a desired state is related to the variables that determine the boundaries beyond which disturbances may push the system into another state (Scheffer & Carpenter, 2003). For example, derelict habitats, especially perturbed due to mining activities, are generated due to discrete destructive events (Sinha, 2008), which have disrupted community structure and changed available resources (Kreb, 2004). They have poor power of resilience to restore their original state (Folke *et al*. 2004; Holling 1973; Gunderson & Holling 2002; Stephen *et al*. 2004; Jackson *et al*. 2001 & Paine *et al*. 1998).

It is pertinent to specify that the derelict ecosystems generated due to mining are different from the degraded habitats in the sense that mining generates habitats with no community and no ecological resilience. It requires human intervention for the restoration of the establishment of the community. There are several studies illustrating ecological systems and the services that they generate and are transformed by human action into less productive or otherwise less desired states (Folke *et al*., 2004). A shift in ecosystem regimes is common due to anthropogenic activities that minimize resilience. It would be important here to clarify between engineering resilience and ecological resilience as defined by Holling (1973), described in his seminal paper – Engineering resilience is a measure of the rate at which a system approaches a steady state after a perturbation, that is, the speed of return to equilibrium, which is also measured as the inverse of return time, whereas ecosystem resilience is the magnitude of disturbance that a system can experience before it shifts into a different state (stability domain) with different controls on structure and function.

In the present paper, the focus will be on the functions and nature of complexities of reclaimed mine spoils (henceforth derelict ecosystems), especially the systems generated due to mining, where there are regime shifts. In these systems, two intrinsic forces – homeostatic and resilient – and one extrinsic force – anthropogenic intervention for conservation have synergistic effects and differ in many respects from other ecosystems taken for understanding the ecosystem functioning.

Further, there is an obvious difference between the resilient and homeostatic forces of a system, which maintains systems in general. Resilience is the capacity of a system to absorb disturbance and reorganize while changing to retain essentially the same function, structure, identity, and feedback (Walker *et al*., 2004), whereas homeostasis is the dynamic equilibrium among the living members of an ecosystem, and with their ever-changing environmental conditions, such as wind, rainfall, nutrient availability, air quality, and climate. Webster's dictionary defines ecological homeostasis as the opposing change to maintain equilibrium. If the system fails to re-establishing its balance, it will be in a state where constraints are more severe than before. This can ultimately lead to the destruction of the system if the disturbances persist.

Folke and co-authors (2004) reviewed several conditions of the regime shift and believe that undesired shifts between ecosystems cause a decline in resilience capacity. They are out of self-repairing mechanisms and cannot correct themselves (Patridge, 2004). The likelihood that an ecological system will remain within a desired state is related to slowly changing variables that determine the boundaries beyond which disturbances may push the system into another state (Scheffer & Carpenter, 2003). In the following sections, we will discuss another force – the third force – generated due to conservation activities, which works as an extrinsic force pushing the system for succession. Consequently, an algorithm has been developed to explain these processes with an example of the derelict ecosystem to understand the ecological functions of a disturbed, especially of the reclaimed mine spoils where the ecosystem is with distress syndrome.

Study area

Overburden dumps are created out of open-cast mining. These overburden dumps by Environmental Law are to be reclaimed so these are reclaimed mine spoils. The present study was carried out in reclaimed mine spoils (RMS) of the Kathara coal mine area during 2006-2008. Experiments were set in four RSM of varying ages from 5 – 50 years along with a natural forest – Taimara reserve forest of Jharkhand. Kathara coal mine area is located at the latitude of 23° 47′ N and longitude of 85° 57′E and it spreads in about a 15-20 km radius (Figure 1). The nature and characters of the selected RSM and the control have been presented in table 1 and 2.

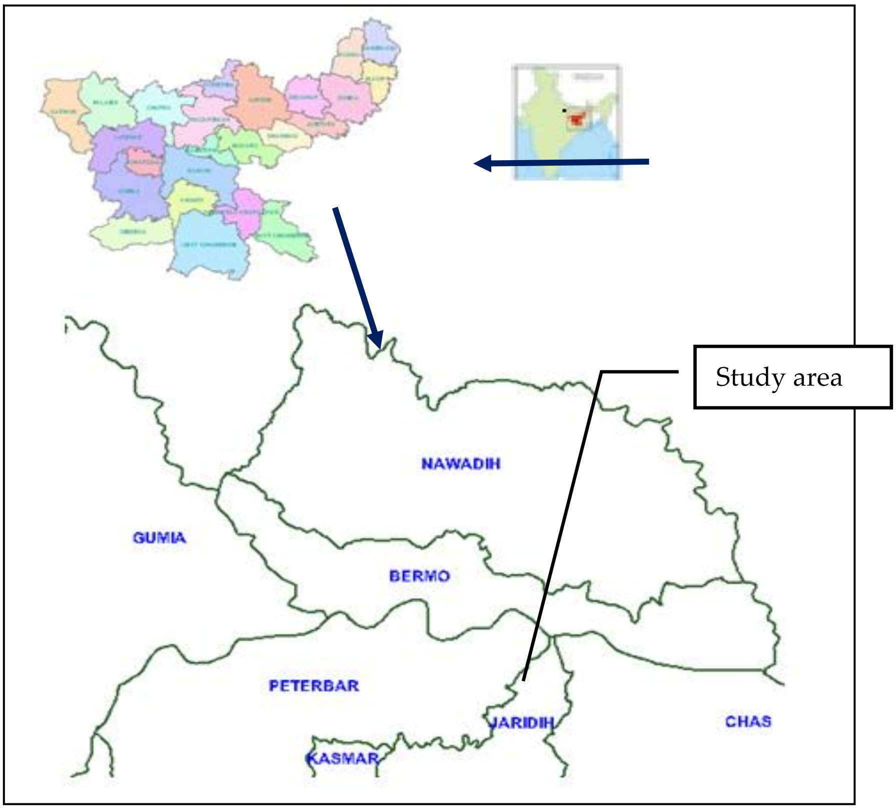

Figure 1. Location map of the study area

Table 1. Selection of sites based on their characteristics for study.

Site No	Age of the site, name, and specification	Nature of perturbation/disturbance in the ecosystem
1	5 years old RMS with fresh plantation	Highly disturbed
2	15 years old RMS with plantation	Less than highly disturbed but more than moderately disturbed
3	30 years old RMS with plantation	Moderately disturbed
4	50 years old RMS with plantation and natural growth	Low disturbed ecosystem
5	A natural forest – with S robusta as the dominant species	Least disturbance or no disturbance in the ecosystem

Table 2. Type of disturbance in the RMS and active or applied forces responsible for secondary succession

	Type of disturbance in the system		
Forces working	**Highly Perturbed & Regime shift systems**	**Moderately perturbed**	**Least perturbed**
Resilience	+++	++	+
Anthropogenic energy as conservation activities*	+++	++	–
Homeostasis	–	++	+++

*Anthropogenic energy or Conservation activities means – the applied human power, fossil fuel and technological inputs applied for afforestation and its maintenance.

Methodology

The soil arthropods were collected from randomized quadrates of 1x1 meter unit cells from each experimental site by using standard pitfall traps (Southwood, 1978). In each pitfall trap jars containing 250 ml of picric acid and formalin mixture were placed in the quadrates. Traps were set in five to six numbers in randomly selected quadrates in each experimental site (Gadagkar et al., 1990). The contents of the traps were collected after 24 -72 hours of setting and stored in 70% isopropyl alcohol. The other methods applied were - nets with a mouth of 30 cm in diameter and bag length of 60 cm were used for sweeping and mechanical hand picking of the arthropods. The animals were later separated from the trash and put in vials containing 70% isopropyl alcohol. After sorting and assigning species numbers, the identification of soil arthropods was done by following Jangi (1996) for scolopendra, Borror et al. (1981) Mani (1978); Zahradnik & Chvala (1989); for insects.

Results

Physico-chemical parameters of the study area have been presented in Tables 3a and 3b. The mean soil temperature in all four sites during the study period varied between 28.6°C to 30.77°C, the mean pH value ranged from 6.7 to 6.7, the mean humidity was between 50.1 to 56.5 per cent and the mean ambient temperature (recorded) was 30.9°C at low and 33°C on the higher side. It is implicit from Table 3b that site I have the highest organic carbon due to high coal content in the soil whereas low organic carbon in site IV implies utilization and cycling of organic carbon, which has been fixed elsewhere in the system. Hence, the system is tending towards restoration, which can be obvious from the Shannon diversity index and Simpson's Index (Table 4 and Fig. 1). Implicitly the quantitative information of Sites one and two (5 to 15 years of plantation) are under stress conditions and are experiencing harsh environmental conditions to support ecosystem functions. Hence most of the rudral species are present (Table 5). Based on the important value index of the species in these sites, the status of the system can be assessed. The presence of species belonging to the orders of Homoptera, Hymenoptera, Isoptera, and Orthoptera with higher IVI is indicative that these sites are in disequilibrium and are under invasion. Further, Site IV and onwards have higher diversity indexes supporting the view that the system is restoring in the process of restoration – shifting from disequilibrium to non-equilibrium.

Table 3a. Physico-chemical parameter of the study area

	Soil Temp.		**pH**		**Humidity**		**Ambient Temp.**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Site I	30.775	±4.025	6.770	±1.007	50.125	±25.525	30.922	±12.205
Site II	30.357	±4.339	6.113	±1.029	47.500	±27.753	32.443	±5.021
Site III	28.943	±4.683	6.125	±0.916	56.500	±28.530	32.986	±2.904
Site IV	28.671	±3.834	6.075	±0.634	53.500	±25.172	33.050	±4.604

Table 3b. Macronutrients of the study area

	OC %		**N kg/h**		**P_2O_5 kg/h**		**K_2O kg/h**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Site I	1.510	±0.245	808.333	±144.597	41.733	±7.692	165.833	±14.770
Site II	1.447	±0.422	766.667	±208.347	40.233	±5.680	160.533	±3.754
Site III	0.917	±0.366	503.333	±178.209	38.900	±2.707	161.100	±9.478
Site IV	0.537	±0.040	316.667	±22.546	36.967	±2.113	150.267	±4.636

Table 4. Diversity index of the study area.

	SI	**SII**	**SIII**	**SIV**	**SV**	**SVI**
Individuals (N)	4277	4989	4825	5838	4919	5078
Shannon index	2.735	2.597	2.622	2.82	2.99	3.142
Simpson index	0.8778	0.8894	0.8694	0.8876	0.8855	0.9179

It was also observed that there is a negative correlation between the diversity index and nitrogen content of the soil and pH (Table 6 and Fig. 2). On cluster analysis (PAST software) it was observed that sites one and two are clubbed together and sites three and four are clubbed together (Fig. 3). These support the fact that harsh environmental conditions prevail in younger age RMS and they are under stress conditions and the system is in disequilibrium. Based on the observation's status, the experimental sites and controls have been drawn and presented in Table 7.

Table 5. Importance value index of a few species collected from different sites

Orders	Important species	IVI
Site I		
Homoptera	*Homoptera* sp.	0.57281
Hymenoptera	*Myrmica rubra*	0.54179
	Formica fusca	0.20813
Orthoptera	*Gryllotalpa* sp.	0.18908
	Gryllus campestris	0.15916
Isoptera	*Mastotermes* sp.	0.13599
Site II		
Hymenoptera	*Myrmica rubra*	0.46215
Isoptera	*Mastotermes* sp.	0.42685
Hymenoptera	*Formica fusca*	0.36467
	Lasius niger	0.31388
Homoptera	*Homoptera* sp.	0.16953
Orthoptera	*Gryllus campestris*	0.16550
Site III		
Isoptera	*Mastotermes sp*	0.90099
Centipedes	*Scolopendramorpha*	0.37762
Hymenoptera	*Myrmica rubra*	0.33102
	Formica fusca	0.20168
Diptera	-	0.11823
Millipedes	*Spirobolus*	0.11108
Site IV		
Hymenoptera	*Formica fusca*	0.33291
	Lasius fuliginosus	0.30054
	Myrmica rubra	0.24260
Isoptera	*Mastotermes* sp.	0.19672
Hymenoptera	*Myrmica sp*	0.14907
Homoptera	*Homoptera*	0.13866
Site V		
Hymenoptera	*Lasius* sp.	0.31390
	Formica sp.	0.24800
	Formica sp.	0.14230
	Camponotus sp.	0.10270
Isoptera	*Mastotermes* sp.	0.13900
	Homoptera	0.12900

Discussion

Case – I. The geomorphic system of the RMS is in disequilibrium (Dutta, 1999). The soil productivity is poor. Mine spoils present very tough conditions for the plants, pedosphere engineers and the sleeping beauties, microbes, to grow and make a conducive environment for secondary succession as nutrients are low (Dutta & Agrawal, 2002). Raising plantations may accelerate the process leading to a self-sustained ecosystem in a relatively short period (Singh & Singh, 1999). Plantations impart a favourable role in the biological reclamation of mine spoil due to modification of the soil characteristics (Table 8).

Case – II. In the case of the forest area, selected for control, had an annual fire (man-made to facilitate the sprouting of S. robusta seeds), where it was observed that although there is a temporary fall in the diversity index, again there is a rise in the diversity index indicating restoration of the forest. The fluctuating nature of the population is indicative that it is controlled by density-independent factors (Kendeigh, 1975) and does not produce stabilization, since they vary in intensity. As no ecosystem is in equilibrium but they are in dynamic equilibrium (Singh et al., 2008). The stability of the ecosystem depends on two factors – resistance, hereafter we will call homeostatic processes and resilience (Holling, 1973). Homeostasis is the ability of the system to maintain itself and resist the forces that tend to cause it to leave its equilibrium (Table 8).

Table 6. Correlation between diversity index and nutrients of the different sites

		Diversity Index	pH	Organic carbon	Nitrogen	Phosphorus	Potash
Diversity Index	Pearson Correlation	1.000	-0.232	-0.671	-0.673	-0.833	-0.894*
	Sig. (2-tailed)		0.707	0.215	0.213	0.080	0.041
	N	5.000	5.000	5.000	5.000	5.000	5.000
pH	Pearson Correlation	-0.232	1.000	-0.270	-0.266	0.128	0.101
	Sig. (2-tailed)	0.707		0.661	0.665	0.838	0.872
	N	5.000	5.000	5.000	5.000	5.000	5.000
Organic carbon	Pearson Correlation	-0.671	-0.270	1.000	1.000**	0.899*	0.866
	Sig. (2-tailed)	0.215	0.661		0.000	0.038	0.058
	N	5.000	5.000	5.000	5.000	5.000	5.000
Nitrogen	Pearson Correlation	-0.673	-0.266	1.000**	1.000	0.902*	0.870
	Sig. (2-tailed)	0.213	0.665	0.000		0.036	0.055
	N	5.000	5.000	5.000	5.000	5.000	5.000
Phosphorus	Pearson Correlation	-0.833	0.128	0.899*	0.902*	1.000	0.984**
	Sig. (2-tailed)	0.080	0.838	0.038	0.036		0.002
	N	5.000	5.000	5.000	5.000	5.000	5.000
Potash	Pearson Correlation	-0.894*	0.101	0.866	0.870	0.984**	1.000
	Sig. (2-tailed)	0.041	0.872	0.058	0.055	0.002	
	N	5.000	5.000	5.000	5.000	5.000	5.000

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

Table 7. Nature of disturbance, the status of the regime, their Shannon diversity index, and Simpson's Index of Diversity

Type of ecosystem	Type of disturbance	Status of regime	Shannon Diversity Index	Simpson Index of Diversity (1-D)
5 – 15 Years old RMS	A high degree of disturbance	Regime shift with the power of resilience	2.735 & 2.597	0.8778 & 0.8894
30 – 50 Years old RMS	Moderately disturbed the system experienced a high degree of disturbance and there had been a regime shift but due to a lapse of time and other anthropogenic activities restoration process of the system is in progress	Time-lapse and the system recoils	2.622 & 2.82	0.8694 & 0.8876
Natural Forest	Start duration disturbance in a system	There is no regime shift	2.99 & 3.412	0.8855 & 0.9179

Conclusions

Based on the foregoing discussions, we concluded that RMS of younger ages is under stress and in disequilibrium. Anthropogenic activities with technological inputs for restoration coupled with natural (intrinsic) – forces lead the system to succession. Some soil arthropods (orders Homoptera Hymenoptera, Isoptera, Homoptera, Coleoptera, Orthoptera (Ensifera and Caelifera) and Araneae) are hard species and can withstand harsh environmental conditions. They are r-select species during their invasive period or during their establishment in the system. They pull the system to recoil and become functionally active. The older reclaimed RMS (30- 50 years old) are functionally active, and the system is in succession. The resilient forces are active and make these systems in a non-equilibrium state. When there are small disturbances or perturbations, as in natural forests, it is homeostasis that restores the system. Based on these findings we can develop a mathematically based ecological model as follows:

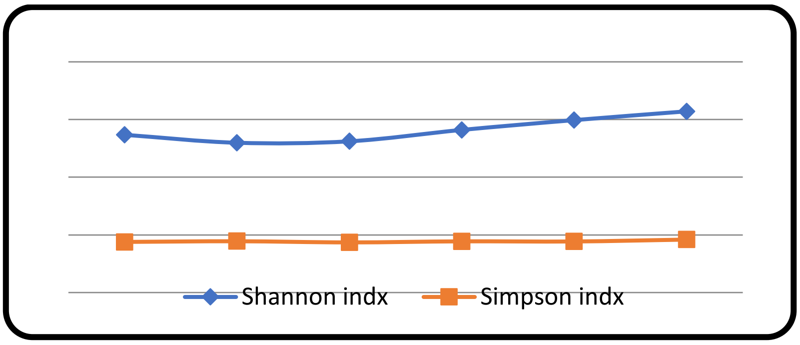

Figure 2. Comparison of diversity indices of all the sites

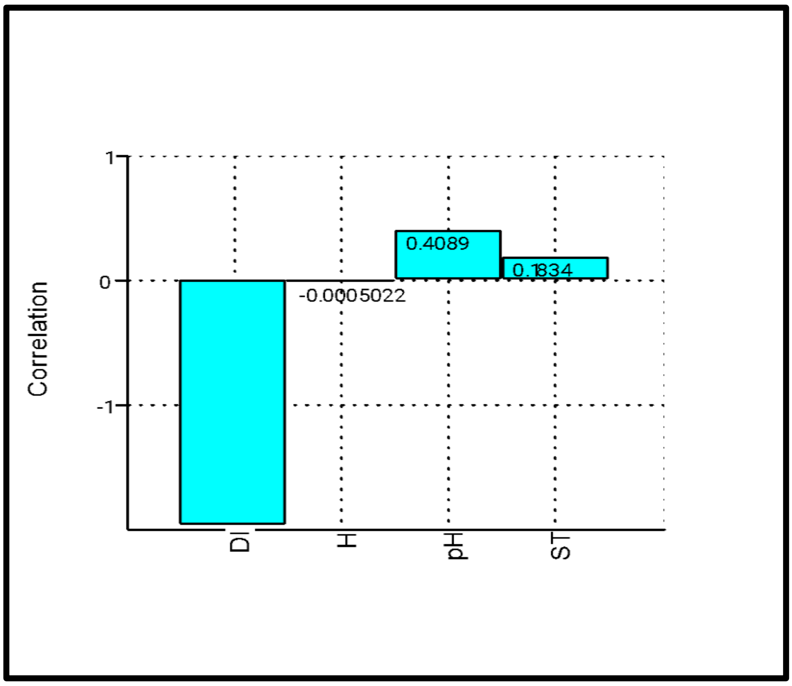

Figure 3. Correlation between diversity index and humidity, pH and soil temp.

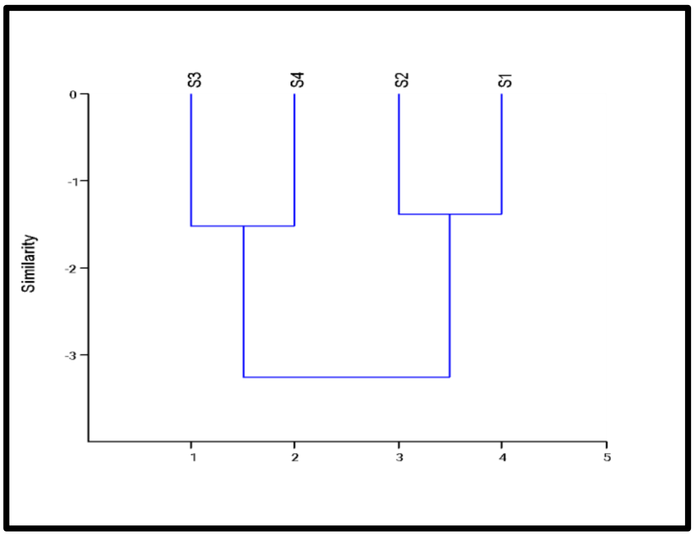

Figure 4. Cluster Analysis to measure the site distance

Table 8. Nature, succession and ecesis in the disturbed ecosystems

Type of ecosystem	Status of succession & process	Ecosystem status	Population type
5 - 15 Years old RMS	Regime shifted system starts recoiling itself due to resilience and conservation activities – secondary succession – pre-sere – an invasion of Rudral species	Population density independent	Domination of r-selected species
30 - 50 Years old RMS	Resilience and the conservation efforts for restoration of systems speed up succession – aggregation of Rudral species	Population density-dependent	r-select species are replaced by K-select species
Natural Forest *	Homeostasis – restores ecosystems from disturbances as the magnitude of perturbation is not high and there is no regime shift	Population density-dependent and density-dependent factors responsible for the maintenance of the population size	The dominance of K-select species

* An ecosystem with the least or no disturbance except for annual fire for forest floor clearance and germination and growth of *Shorea robusta* seeds

Ecological Model

When a habitat like a natural forest (an ecosystem) its homeostatic processes keep it in dynamic equilibrium and the homeostatic processes (force) of a system are greater or equal to the resilient forces of that system then the system is in equilibrium, and it can be expressed as follow:

$$\text{When } D_H \geq D_R \rightarrow S_E \quad \text{\_\_\_\_\_\_\_\_\_\_} (1)$$

Where D_H = Homeostatic process in Derelict Ecosystem

D_R = Resilience force of a derelict habitat

S_E = A habitat (System) in Equilibrium

When the Homeostatic processes are lesser than the resilient forces of the system then the system changes into non-equilibrium and it can be expressed in the following terms

$$\text{When } D_H < D_R \rightarrow S_{NE}, \quad \text{\_\_\_\_\_\_\_\_\_\_} (2)$$

NE = Non-equilibrium

What are resilient forces in the natural system?

The ability of a system to return to its original state of equilibrium following perturbations with rapidity and ease is known as the power of resilience of a system. But this never happens. As the perturbations are not only due to natural forces but may be coupled with anthropogenic activities, hereinafter we will call these anthropogenic activities as technological advancements (T A).

When in a system there are inputs due to technological advancements in the systems (Ecosystems), it forces the system for change – succession. Therefore, a system with the power of resilience coupled with TA loses its capacity to return to equilibrium and tends towards succession. This can be expressed as follow:

$$S_{NE} = \Sigma D_R + \Sigma D_T \quad \text{\_\_\_\_\_\_\_\_\_\_} (3)$$

Where S_{NE} = System in non-equilibrium

D_T = Anthropogenic forces – technological advancements and inputs in the system

Therefore,

$$\text{If } D_H < S_{NE} \rightarrow \sigma \quad (4)$$

Then there is Succession

For the explanation of the above equation

We have

$$D_H \rightarrow S_E \quad (5)$$

A system will remain in a homeostatic state if its keystone/important species are not disturbed or removed (Paine, 1966, 1980) and the natural network (NNW) is maintained.

This is a hypothetical state and practically it never happens in the system. It can be viewed in the light of equation no. 3. Therefore, all systems are in non-equilibrium due to anthropogenic activities (technological advancements) and especially the derelict ecosystems created due to mining and other processes and the NNW is broken and the natural network of a system (NNS) is leading to non-equilibrium.

Further, a system will proceed to non-equilibrium if its keystone species are removed (Paine, 1966, 1980) but due to heterogeneity (species diversity, spatial heterogeneity, and genetic heterogeneity) proposed by (Mac Arthur and Mac Arthur, 1961) of a large system will prevent it from catastrophic consequences due to perturbations (O'Neill and Reichle, 1980).

But in the present case, the situation is different due to its nature as the RMS is a disturbed system and there has been plantation along with technological inputs for supporting the growth of the plants which attracts the organisms to explore a new habitat. The present situation is of high stress and high disturbance, which is harsh for colonization. In these situations, the rudral species (R) like r-select species colonize the disturbed/ harsh patches (Singh et al., 2008).

As the resilience of a system has been attributed to r-select species (O'Neill and Reichle, 1980), therefore, the dominance of r-select species in the system reflects in equation no. 3.

Chapin et al. 1996 said that there are five dynamic interactive controls regulating ecosystem processes – these are local climate, supply of resources, functional groups of organisms, disturbance regimes and human activities. Further, a gain or loss of a functional group can change the ecosystem properties and processes through changes in species traits, resource supply and disturbance regime variables (Hooper and Vitousek, 1997). The disturbance is critical for sustaining ecosystem structure and process rates. The intensity and frequency of disturbance can cause long-term ecosystem change. Human activities are the prime ecological drivers of degradation and rehabilitation of ecosystems (Singh et al., 2008). Therefore, it is imperative from the ongoing discussions and the mathematical model derived out of the functions that the RMSs are under ecological stress and the ecological forces – homeostasis and resilience of the system try to restore them. Further, more studies are required to see the population dynamics and their role in the above phenomenon.

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