Plant-microbial Community Dynamics Associated with Soil Nutrient Gradients in Newly Rehabilitated Degraded Land

A Case Study from the Indian Central Himalayas

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Abstract

In the mid-hills of the Indian Central Himalayas, there is paucity of information about the biophysical rates of recovery when degraded areas are rehabilitated. This study presents an analysis of change in terms of floral communities and associated change in soil character within an area of land under rehabilitation that was used extensively for grazing in prior times. During the last six years (1993-98), factors related to the Importance Value Index (IVI) of plant species, the densities of various microbial organisms, and the soil character were measured with a view to recording rates of improvement in soil fertility, colonisation of comparatively useful species, and biomass.

Introduction

The most spatially and economically important human uses of land include cultivation in various forms, livestock grazing, settlement and construction, reserves and protected lands, and timber extraction. These and other land uses have cumulatively transformed land cover on a global scale (Turner *et al.* 1994). Destruction of forests for agricultural expansion to support a growing human population has been prevalent in the Hindu-Kush mountain ecosystems (Rawat *et al.* 1997). Many of these cleared areas revert to secondary ecosystems when left abandoned. Such lands are centres of evolution for many grasses, herbs, and microbes, and because they have developed into important and influential ecosystems, it is useful to have quantitative and qualitative information about them. Much contemporary research in the central Himalayan mid-mountains focuses on understanding of how the nutrient cycles of different ecosystems respond to environmental disturbances, but there is a paucity of studies on biodiversity, ecological dominance, and the physiological responses of floral communities within degraded areas. It is well known that disturbances in any stable ecosystem have a negative effect on the entire biome, and that soil characteristics are immediately affected. The loss of closed forest canopy results in the exposure of soils, and as a result the organic matter they contain becomes vulnerable to oxidation. When subjected to uncontrolled grazing these areas undergo a series of modifications as a result of the loss of the insulating effect from vegetation, an altered moisture infiltration rate, and soil nutrient losses. Subsequently, floral communities develop that are characterised by strategies that enable them to survive and produce seed. The present study focuses on the changes in floral communities and soil characteristics over a period of six years within a rehabilitated area previously degraded by overuse and overgrazing.

Study Site

The study site, called Balgara, has a total area of nine hectares, and is located in Arah village, which lies in the Indian central Himalayan mid mountains, between 29° 59'30" and 29° 59'56" N and 79°35'20" and 79°36'15" E. The region as a whole is characterised by a variety of microclimates, mainly governed by geographical coordinates and altitudinal variations. The study site faces NE and lies at an altitude of 1490 masl. The temperature drops to just 0°C during winter and reaches a maximum of 37°C during summer. The area receives moderate precipitation (mean annual value 1,380 mm).

Site History

- Until 1950—under forest dominated by *Pinus roxburghii*
- During the 1960s—site cleared for agricultural activities
- Until 1975—agriculture practised, partially under irrigation
- After 1975—area abandoned as a result of fragmentation of land holdings, distant location from the main village of Arah, increase of out-migration of males, a scarcity of water for irrigation, and destruction of crops by monkeys; became an open grazing area
- 1993-1996—area selected for a rehabilitation project funded by IDRC; the concept of land consolidation and community management was introduced, and preferred fuel, fodder, and timber species were planted; water harvesting practices and a complete halt to open grazing were introduced with the help of the *van panchayat* and the villagers
- From 1996-1999—area managed by the community and monitored by the GB Pant Institute of Himalayan Environment and Development as part of the People and Resource Dynamics Project (PARDYP)

Materials and Methods

The experimental area covered about 1/2 ha in the upper portion of the site where no active plantation had been done. It was divided into ten sectors. The plant/microbial populations and changes in soil characteristics in the sectors were studied from 1993 to 1998.

For phytosociological studies, 50x50 cm quadrats were laid within each plot during the first week of October (post-monsoon period) each year. This sampling coincided with the peak live biomass of ground vegetation, mainly grasses and herbs. Vegetation was clipped to ground level, and each species was separated and taxonomically classified into C_3 and C_4 species following Raghvendra *et al.* (1978), Naithani (1984, 1985), Chowdhery *et al.* (1984), Babu (1977), and Samant (1987).

Analytical features such as density, frequency, abundance, and importance value index (IVI) were determined following Misra (1968) and Saxena and Singh (1982). Tillers of the grasses were counted to measure densities and a digital vernier caliper was used to measure the diameter of each recorded species.

Three groups of soil microorganisms (fungi, bacteria, and actinomycetes) were enumerated in triplicate using the serial dilution technique (Johnson 1972). Mycological agar, nutrient agar, and actinomycetes isolation agar (from Hi Media, Bombay, India) were used to culture fungi, bacteria, and actinomycetes, respectively. Bacteria and actinomycetes were identified on the basis of their colour and shapes, and fungi were identified following the methods of Gilman (1987), Ellis (1971), Booth (1971), Barnett (1960), and Pitt (1979).

Soil samples were collected from study plots from 0-30 cm depth. Plant litter (the undecomposed and semi-decomposed top layer) was removed from the soil surface before each core was collected. Analyses of the soil parameters were done following the methods of Allen (1989).

Results and Discussion

Community Composition Changes

The importance value index (IVI) of the different species identified at the site were recorded each year from 1993 to 1998 (Table 94). The dominant species recorded at the site was *Imperata cylindrica*, a C_4 grass species. It had a maximum IVI value of 128 in the first study year (1993) which fell with each succeeding year to 108 in 1998. Twenty-eight species were recorded in 1993 and this increased to 52 in 1998. The number of C_4 species recorded increased from two in 1993 to eight in 1996/98; but the total IVI values of these species dropped from 150 in 1993 to 130 in 1998 (150, 142, 138, 133, 133, and 130).

Table 94: **Changes in the Importance Value Index (IVI) of Plant Species from 1993 to 1998**

Species Name	1993	1994	1995	1996	1997	1998
Chrysopogon serrulatus C_4	21.3	20.1	14.54	11.71	11.05	9.15
Imperata cylindrica C_4	128.5	122.1	121.76	112.74	110.24	108.23
Euphorbia prolifera	11.24	10.8	5.35	5.32	4.11	3.21
Indigofera dosua	38.76	43.8	45.47	44.64	44.74	44.98
Gnaphalium hypoleucum	4.2	2.1	1.48	1.44	1.19	1.08
Erianthus rufipilus	19.11	17.7	17.21	16.21	16.26	16.34
Adiantum lanulatum	1.0	2.2	2.53	2.79	3.84	3.46
Origanum vulgare	3.0	2.0	3.66	4.2	3.94	3.9
Cheilanthus albomarginata	1.27	1.3	2.18	2.73	3.94	3.89
Gloriosa superba	2.0	1.9	1.4	1.14	1.98	1.79
Oxalis corniculata	6.0	7.8	8.46	7.53	7.56	7.89
Potentilla fulgens	4.06	5.02	6.47	5.16	5.21	5.01
Crotalaria semialata	3.23	5.3	3.83	5.58	4.16	4.9
Micromeria biflora	8	8.6	8.26	8.49	9.94	8.56
Phyllanthus simplex	2	2	2.64	1.05	1.04	1.21
Calamintha umbrosa	3	2.08	2.26	2.57	2.96	2.89
Craniotome furcata	1	1	0	1.14	0	0
Cassia mimosoides	7.6	11.45	11.31	11.22	9.45	9.46

Table 94: **Changes in the Importance Value Index (IVI) of Plant Species from 1993 to 1998 (cont'd)**

Species Name	1993	1994	1995	1996	1997	1998
Flemingia sambuense	1	1.1	0	1.2	0	0
Pareitaria debilis	2	2.3	3.86	3.18	1.61	0.78
Desmodium triquetrum	10	11.3	14.07	10.74	8.14	8.67
Begonia picta	3.56	3.3	4.06	4.29	4.4	3.56
Drosera peltata	6.21	4.3	1.23	0.18	0.16	0.12
Artemisia parviflora	2.04	2.1	2.35	1.26	0.15	0.34
Erigeron Canadensis	4	4.7	3.66	3.78	2.94	2.99
Polygala abyssinica	1	1.5	0.85	0.24	1.89	1.34
Scrophularia calycina	3.63	1.01	1.13	1.8	1.08	1.34
Crotalaria sessilifera	1	2	1.38	2.19	1.9	1.07
Fimbristylis miliacea C_4	0	0	2.15	1.98	0.87	1.34
Barlaria cristata	0	0	1.38	1.89	1.64	1.34
Centranthera nepalensis	0	0	1.42	1.47	1.49	1.34
Erigeron bonariensis	0	0	1.53	0.66	0.94	0.9
Androsace rotundifolia	0	0	2.63	1.95	1.42	0.9
Arundinella nepalensis C_4	0	0	0	0.36	1.89	1.67
Bothriochloa pertusa C_4	0	0	0	0.9	1.9	1.78
Cyperus compressus C_4	0	0	0	2.4	2.42	2.23
Dicanthium annulatum C_4	0	0	0	1.86	2.94	2.34
Setaria glauca C_4	0	0	0	1.08	1.25	2.89
Fimbristylis ovata	0	0	0	0.48	1.19	1.9
Cynoglossum zeylanicum	0	0	0	1.2	0	0
Valeriana wallichi	0	0	0	1.44	1.96	2.09
Justicia pubigera	0	0	0	0.93	0	0
Polygonum nepalensis	0	0	0	0.84	1.38	1.01
Cyanotis vaga	0	0	0	1.05	1.06	0.56
Lindernia sessilis	0	0	0	0.9	1.84	0.34
Euphorbia hirta	0	0	0	0.21	0	0
Zornia gibbosa	0	0	0	1.65	2.94	1.98
Evolvulus alsinoides	0	0	0	1.86	3.36	2.32
Justicia simplex	0	0	0	0.42	0	0
Lindernia crustacea	0	0	0	1.68	2.74	0.89
Heteropogon contortus	0	0	0	0	3.36	3.98
Bidens pilosa	0	0	0	0	2.96	3.13
Conyza stricta	0	0	0	0	0	0.67
Crotalaria albida	0	0	0	0	0	0.12
Arthraxon nudus	0	0	0	0	0	0.15
Lespedaza gerardiana	0	0	0	0	0	0.78
Antirhinum orontium	0	0	0	0	0	0.56
Apluda mutica	0	0	0	0	0	0.23

C_4 indicates species with a C_4 pathway

One of the most important indicators of soil fertility is the microbial population (Table 95). The microbial population density increased continuously from 1993 to 1998 with the maximum increment recorded during 1993-94 (39% and 18% for fungi and bacteria respectively). The genera *Penicillium and Aspergillus* dominated the populations (Table 96).

Table 95: **Microbial Population, Colony Forming Units per Gram of Dry Soil**			
Year	Fungi (x 10^3)	Bacteria (x 10^5)	Actinomyceles (x 10^5)
1993	74	95	20
1994	103	112	39
1995	122	129	44
1996	139	154	51
1997	147	158	54
1998	152	161	55

Table 96: **Identified Fungal Species—Colony-Forming Units per Gram of Dry Soil**						
Species names	1993	1994	1995	1996	1997	1998
Absidia sp.	0.13	0.33	0	0	0	0
Alternaria alternata	0.51	0.55	0.61	0	0.25	0.63
Aspergillus niger	0.13	0.64	1.35	1.76	2.39	2.29
Aspergillus flavus	0	0.66	0.37	0.23	0.12	0
Aspergillus fumigatus	0.64	0.64	0.73	1.06	0.37	0.25
Aspergillus sp.	0	0	0	0.23	0.88	0.88
Botrytis sp.	0.38	0.93	0	0	0	0
Cladosporium sp.	0.25	0.66	0.87	0.95	0.62	0.5
Colletrotricum sp.	0.25	0	0	0	0	0
Curvularia sp.	0	0.11	0	0	0	0.12
Drechslera sp.	0	0	0.24	0	0	0
Fusarium sp.	0	0	0	0	0.12	0.25
Gliocladium sp.	0	0.33	0	0	0	0
Helminthosporium sp.	0.38	0.44	0	0	0	0
Hormodendrum sp.	0	0.11	0	0	0	0
Mucor sp.	0.13	0.11	0.12	0.58	0.62	0.55
Penicillium expansum	2.19	1.21	2.69	2.84	2.27	2.29
P. chrysoginium	0	0.11	0.75	0.12	0	0
P. sp.	0	0.87	0.12	0.58	0.75	1.26
Paecilomyces sp.	0	0	0	0	0.5	0.76
Rhizopus sp	0	0	0.12	0.58	0.37	0.25
Trichoderma koningi	0.88	0.55	1.24	1.41	1.26	1.52
T. harzianum	0.64	0.33	0.36	1.06	0.5	0.13
Monila sp.	0	0.11	0	0	0	0
Verticillium sp.	0.25	0	0	0	0	0
*White sterile mycelia**	0.64	1.22	1.86	1.65	2.51	2.29
*Grey sterile mycelia**	0	0.37	0.75	0.83	0.37	0.88
*Black sterile mycelia**	0	0	0	0	0.75	0.38
* Specific identification was not possible because there was no sporulation						

Changes in Soil Nutrients

The soil chemical and physical conditions improved during the six-year study period (Table 97). There was a significant increase in soil moisture, organic carbon, total nitrogen, available phosphorus, and available potassium, and the pH improved from 5.9 in 1993 to 6.2 in 1994, remaining more or less constant thereafter.

Table 97: **Changes in Soil Properties from 1993 to 1998**						
Year	Moisture %	pH	Organic Carbon %	Total Nitrogen %	Available Phosphorus (kg/ha)	Available Potassium (kg/ha)
1993	12.3	5.9	1.02	0.012	7.2	134
1994	19.9	6.2	1.08	0.012	8.9	157
1995	20.1	6.3	1.12	0.022	9.2	189
1996	20.6	6.4	1.44	0.019	9.2	181
1997	21.2	6.4	1.44	0.021	11.1	190
1998	21.4	6.3	1.45	0.021	11.4	192

Discussion

The species composition within any ecosystem is strongly influenced by multiple factors including soil characteristics (Tilman 1990; Tilman and Wedin 1991), grazing (Rana and Rekhari 1994), climate (Teeri and Stowe 1976), and altitude (Tiezsen *et al.* 1979). This study provided significant information about changes in the characteristics of a particular ecosystem that had been under significant grazing pressure for a long time. The dominance of C_4 plant species and their changing status from 1993 to 1998, associated with changes in edaphic characteristics, agree with the findings of others who have compared plant community differences in relatively productive and unproductive sites. For example, a greater proportion of C_4 species is found in drier and low nitrogen soils (Black 1973; Tilman *et al.* 1996). Plants with a C_4 pathway possess a carbon concentrating mechanism in their bundle cells, and it is this unique feature that confers on them the adaptive advantages to survive in habitats with high temperatures, high irradiation, low soil nitrogen, and low moisture (Epstein 1997).

Imperata cylindrica and *Chrysopogon serrulatus* are the key species dominating the colonisation of such sites because of their higher water and nitrogen use efficiencies. *Imperata has a* vigorous root system and does not require precipitation to grow initially. Its sharp panicles cause problems for grazing by animals, this being a biological adaptation for survival.

Under heavy grazing pressure, even moderately resistant species may be eradicated if they are palatable. As a result, any species that is grazing intolerant is unable to colonise and, by the same token, species that are tolerant (or resistant) to grazing predominate. Grazing restricts the distribution and performance of potential competitors, allowing graze-tolerant or resistant species to spread. Moderate or heavy grazing pressure can significantly alter the relative abundance of graze-sensitive, graze-resistant, and graze-tolerant species within a community.

In this study, the emergence of new species from 1993 to 1998 after relief from grazing pressure corresponds to general findings that within a small enclosure, after relief from grazing, the species sensitive to grazing re-establish themselves in the secondary succession. Improvement in soil conditions also assists in the establishment of new species. Species may colonise an area if there are sufficient soil nutrients; but they may also become locally extinct because of dry conditions (Piper 1995).

The increase observed in the biodiversity during the study period is significant because it has been proven experimentally that more species-diverse plots use and retain nutrients more efficiently than do less species-diverse plots (Kareiva 1996), i.e., they become more productive. The increase in soil nutrients and moisture also plays a key role in increasing the microfloral population and activities. The abundance and physiological activity of the microflora in different habitats varies considerably, and these communities and their biochemical activities undergo appreciable fluctuations with time at any single site. Both generic composition and densities vary with soil physical and chemical characteristics (Gujaratis 1968; Misra 1966; Misra and Srivastava 1970; Rao 1986). Despite its small and variable mass, the microbial population is a very important constituent of a productive eco-system (Swift 1976). Its function is often compared to a sink and transformation strainer through which, sooner or later, all the carbon originating from the dead organic material passes (Paul *et al.* 1979). This microbial biomass responds sensitively to changes in the amounts and distribution of available carbon substances in an ecosystem.

Conclusion

Any ecosystem can be disturbed by changes in land use. A disturbance can turn an ecosystem into a battlefield between the forces of negentropy and entropy, or between development of an ecosystem organisation and its diminishment (Odum 1969). Every system is subject to an array of external inputs, for example water, radiant energy, wind, and gravity, all of which represent potential destabilising forces that may destroy or diminish the ecosystem organisation or damage its building bricks. For an ecosystem to maintain itself or grow, it must channel or fight these destabilising energetic forces in such a way that their full destructive potential is not achieved.

The dominance of C_4 species at the study area near Arah village suggests that degraded lands exposed to excessive grazing pressure still possess the potential to develop strategies to cope with or resist destabilising forces. The site is degraded in terms of soil condition, but the dominance of C_4 plants enables the ecosystem to sustain itself by drawing on a bank of energy and nutrients built up over a long period of time to solve immediate crises that may threaten still greater damage.

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