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SPATIO-PERSISTENCE DYNAMICS OF PLANT SPECIES ON METAL CONTAMINATED SOILS AROUND NULLAH LEH OF RAWALPINDI, ISLAMABAD, PAKISTAN

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Abstract

The metal contaminants in soil can influence the natural dynamism in plant populations. Different sources of metal contaminants were considered that had raised the soil toxicity level affecting plant distribution on a small scale. The course of natural succession was then monitored based on site specific conditions and comparative account was highlighted to reveal the metal toxicity threshold. It seems that contaminated areas, where regional persistence is governed by the processes of patchy colonization are leading to an ill-defined mosaic of suitable and unsuitable habitat. Overall, species richness is on a decline and spatially extended plant populations are essentially a simple extension of local dynamics occupying a small tract of suitable habitat. Although a range of forms of local spatial dynamics exists, these are qualitatively different from the forms of population structure at regional level. This shows the impact of metal pollutants on landscape, which is in fact a reflection of measurements made of (i) plant diversity across the landscape (including both contaminated and reference sites) and of (ii) spatial heterogeneity. In the present study, an important ecological relevance is structured among influence of heavy metal pollutants on soil system and ecological functioning of plants.

Introduction

The concept of suitable habitat for the establishment of plant communities for naturally occurring vegetation types is the basis of plant ecology. In other words, the prevailing vegetation type in an area is considered best adapted to the existing environmental conditions. However, the effect of habitat deterioration often results in heterogeneous trends. At present, the imminent challenge in plant ecology is the understanding that how patterns and processes vary with environmental gradients (Rydgren *et al*., 2003), and prediction of phytosociological trends that determine the species composition of communities. Before generating any hypothesis in functional ecology, description of patterns in species assemblages and diversity is an essential step (Jonsson & Moen, 1998), as well as analysing any relations between plant communities and ecological processes (Schluter, 1984). Several studies concerning ecological processes that influence species diversity and patterns are documented (Malkinson *et al*., 2003). It is a common observation that changes in vegetation structure and composition driven by biotic or physical stress often results in complex and unpredictable trends. Soil contamination by heavy metal is one of such stresses that lead to the plant dynamics in spatial context. The distribution and dynamics of plant species at variable scale in spatial perspectives has been the focus of many studies (Pacala, 1986; Bascompte & Solé 1995). Questions concerning the metal toxicity in soil and plant distribution have been particularly influenced in terms of habitat alteration rendered to a gradual shift from suitable to unsuitable state. Therefore, the magnitude of soil contamination is of prime importance in order to investigate the threshold limits of species persistence and dynamics at local plant community level.

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Soil metal contamination is particularly important from Pakistan's perspective as a large number of industries often discharge their waste untreated in open environment (Mahmood *et al*., 2000). From local perspective, the Industrial Area Islamabad which lies in the Federal capital, collects a variety of waste waters in the main water channel 'Nullah Leh' and passes through urban centre i.e., Rawalpindi city. The Nullah Leh eventually ends up in River Soan but in the monsoon season, it overflows and causes considerable damage to adjacent land areas, vegetation and dwellings (Mian *et al*., 1998). Soil along Nullah Leh has increasingly become contaminated and many toxic elements had also been reported in the water of this drain (Rashid *et al*., 2001). Vegetation growing along this water drain reflects the influence of pollutants that are constantly being added in soil making the naturally occurring plant species to develop a strategy for community development.

For this purpose, small-scale spatial structures of communities must explicitly be taken into consideration. Spatial heterogeneity of vegetation usually occurs in two dimensions: a vertical, corresponding to vegetation stratification, and a horizontal which consists of a mosaic of plant communities determined by the heterogeneity of both biotic and abiotic factors, mainly microclimate and soil (Packam *et al*., 1992; Rosenzweig, 1995). Consequently, many environmental gradients influence vegetation pattern both at a micro- and macro-scale and plants may be influenced by these gradients more or less sharply (Day *et al*., 1988; Baker 1989; Short & Hestbeck 1995; Stohlgren *et al*., 1997). For example, vegetation around zinc and copper smelter is typically sparse and derelict in appearance (Buchauer, 1973). Trees show drastic stunted growth compared to herbaceous flora. Habitat destruction by landscape alteration or soil contamination may threaten species diversity (Schamp *et al*., 2003). Keeping in view the fragility of ecosystem dynamics and habitat intactness at localized scale, the present study was designed to determine threshold limits for native vegetation that can persist in contaminated areas. A further step aimed to show the distribution pattern of species along environmental gradients that were investigated in this study to highlight any particular factors responsible for stress imposition on native vegetation.

Materials and Methods

The study was conducted along the Nullah Leh, which passes from industrial area of Islamabad and Rawalpindi cities. Along its way it receives effluent waste from several industries of Islamabad as well as sewage water of Rawalpindi city. Eventually, Nullah Leh ends up in Soan River. During this study, four stands were demarcated for vegetation sampling along Nullah Leh in industrial area of Islamabad region. The quadrat method was applied to estimate the phytosociological parameters. About 60 quadrats (1 x 1 m size) were sampled and attributes like cover, density, frequency and relative abundance were noted. Stands used for vegetation analysis were subjected for soil sampling as well. A composite soil sample was obtained from 6 quadrats of closest vicinity. Some physical (texture) and chemical characteristics of soil (organic matter, pH) and total heavy metal contents were analysed (Carter, 1993) to reveal the edaphic conditions of the area. Ordinations were performed (Ter Braak, 1987) to correlate distribution and relative abundance of plant species with edaphic characteristics.

Table 1. Occurrence of species in four stands sampled by obtaining 60 quadrats and their phytosociological attributes.

Species	(n)	Plant Cover (%)	Frequency (%)	Density plants/m^2
Achyranthes aspera L. (Amaranthaceae)	08	9	18.3	0.13
Atriplex crassifolia C.A.Mey. (Chenopodiaceae)	14	22	43.3	0.23
Calotropis procera (Willd.) R. Br. (Apocynaceae)	05	13	6.6	0.08
Crotalaria medicaginea Lam. (n = 07) (Fabaceae)	07	11	13.3	0.12
Cynodon dactylon (L.) Pers. (Poaceae)	79	55	93.3	1.32
Dichanthium annulatum (Forssk.) Stapf (Poaceae)	63	37	85.0	1.05
Dichanthium foveolatum (Delile) Roberty (Poaceae)	17	8	40.0	0.28
Digera muricata (L.) Mart. (Amaranthaceae)	09	7	23.3	0.15
Dactyloctenium aegyptium (L.) Willd. (Poaceae)	12	6	33.3	0.20
Imperata cylindrica (L.) P. Beauv. (Poaceae)	11	9	21.6	0.18
Malvastrum coromandelianum (L.) Garcke. (Malvaceae)	10	14	18.3	0.17
Oxalis corniculata L. (Oxalidaceae)	14	5	31.6	0.23
Parthenium hysterophorus L. (Asteraceae)	23	22	28.3	0.38
Saccharum bengalense Retz. (Poaceae)	26	32	45.0	0.43
Suaeda fruticosa (L.) Forssk. (Chenopodiaceae)	18	14	30.0	0.30
Trifolium alexandrinum L. (Fabaceae)	29	20	53.3	0.48

'*n*' is total number of plants in all quadrats.

Table 2. Soil characteristics of different stands of the study sites. Mean ± SD.

Sites	Soil pH	Organic matter (%)	Soil texture	Particle size (%)		
				Sand	Silt	Clay
Stand 1	7.7 ± 1.1	1.12 ± 0.4	Sandy loam	68 ± 7	21 ± 5	11 ± 4
Stand 2	6.8 ± 0.6	3.35 ± 0.8	Sandy clay loam	56 ± 9	22 ± 5	22 ± 5
Stand 3	7.1 ± 0.8	2.04 ± 0.5	Sandy loam	72 ± 8	12 ± 2	16 ± 4
Stand 4	6.0 ± 0.7	0.95 ± 0.1	Sandy loam	73 ± 7	16 ± 3	11 ± 3

Results

Data regarding vegetation analysis are presented in Table 1. Among most frequently observed species are the members of grass family. The frequency of occurrence ranges form 6.6 to 93% and only three species showed frequency of occurrence greater than 50% (Table 1). The floristic composition encountered during vegetation analysis showed that members of the family Poaceae were dominant as out of total 16 species, 6 species of grass family were observed. Amaranthaceae appeared second most dominant family while for Chenopodiaceae and Fabaceae 2 members from each were observed during quadrat analysis. Among all the species *Cynodon dactylon* and *Dichanthium annulatum* were on the top with maximum density and percentage cover compared to other species (Table 1). Overall plant biodiversity of the four stands studied appeared to be mainly comprising of herbaceous flora as most of the species encountered during vegetation sampling were of less than three feet high. Minimum density was observed for those species that attain height of four feet or more except for *Saccharum bengalense*. In terms of height another species i.e. *Calotropis procera* occupied considerable cover values however, its density and frequency were the least (Table 1). Rest of the species were either creeping in habit or making low prostrate stature thus lacking entire stratification in the observed stands.

As far as edaphic features are concerned the texture was more or less same with some variations in soil organic matter contents (Table 2). From stand 4, lowest organic matter content was recovered as compared to the other stands. The soil pH however ranges between pH 6.0–7.7 in all the four stands (Table 2). The particle size distribution indicates that course textured soil is mainly present in these stands with sand and silt particles making 80% of the soil proportion (Table 2).

Regarding soil contamination for heavy metals, it was observed that stand 3 is comparatively least polluted. However, Zinc (Zn) concentration was maximum i.e., 26.2 mg kg^{-1} in this stand (Fig. 1). Maximum values of Lead (Pb) were observed in stand 2 while an intermediate range (1.8 to 3.8 mg kg^{-1}) of Cadmium (Cd) and Iron (Fe) concentrations were found in all stands (Fig. 1). Distribution of species along environmental gradients indicates varying degree of sensitivity. A fairly high degree of ordination was observed for soil organic matter contents. Plant assemblages were most crowded initially when organic matter in soil remained less than 3% while at few spots where organic matter was relatively higher, *Cynodon dactylon* and *Suaeda fruticosa* were found associated with each other (Fig. 2a). The distribution pattern of species along soil pH gradient seems to be following a definite pattern in the ordination diagram (Fig. 2b). Species tend to remain in group and a cluster was observed around pH 7 and within this group of species *Dichanthium annulatum* and *Parthenium hysterophorus* were observed towards higher abundance region (Fig. 2b). The relationship between species distribution and abundance with respect to soil heavy metals was patchy in appearance (Fig. 2c). *Oxalis corniculata* and *Cynodon dactylon* were preferably abundant at lower soil heavy metal containing spots while metal enriched spots were particularly dominated by *Dichanthium annulatum* followed by *Atriplex crassifolia* and *Parthenium hysterophorus*. At few instances, *Trifolium alexandrinum* did show its ability to withstand higher soil heavy metal concentration due to its occurrence along varying soil metal containing spots (Fig. 2c).

Discussion

Vegetation growing in areas along the Nullah Leh is responding to contamination stress as well as to the disturbance factor. Its response is similar to that of vegetation found on a wide variety of anomalous soils such as eroded soil, cleared land and industrial effluent polluted soils. The source of soil contaminants is obviously polluted water of Nullah Leh that has rendered the area in general and soil environment in particular unsuitable for the colonization of native species. The phytosociological attributes of plants presented in Table 1 indicate that cover values corresponding to the number of individuals are in the direction of sparse type of vegetation. Moreover, plants are less frequently found in quadrats although a moderate increase in diversity of species was observed as we moved away from Nullah Leh. The stands demarcated for sampling also revealed variable results for soil metal contamination (Fig. 1). It seems that stand 3 is relatively least metal contaminated except for Zn concentration while rest of three stands reflected variable status for heavy metals in their soils. One of the striking features at these stands is the response of different plants to individual metals. Majority of the species showed a trend of Zn tolerance although out of total 16 species recorded and 10 ordinates were assembled to establish a relationship among these species growing in the area and site characteristics (Fig. 2). The emerging pattern is a manifestation of vital role that edaphic features play in species distribution. The response of various species to soil organic matter contents and pH values reflect plant’s sensitivity to these environmental gradients. Some of them were found less sensitive, for instance grass species viz., *Dichanthium annulatum* and *Dichanthium foveolatum*. The frequent occurrence of these species (Table 1) may represent their inherent ability to withstand soil pollution as grass species are considered more tolerant to soil metal contamination (Wickland, 1990). On the other hand evidence of limited or restricted species distribution was revealed due to

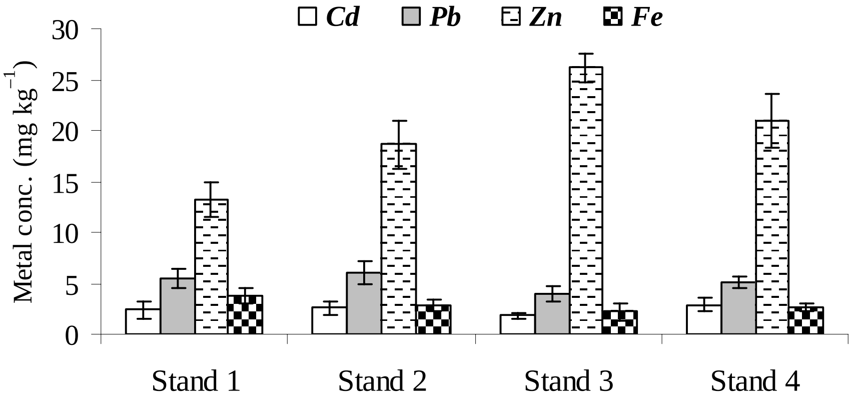

Fig. 1. Soil metal concentrations at different stands along an industrial effluent-water receiving channel (Nullah Leh). Concentration of metals (mg kg^{-1}) on dry weight basis.

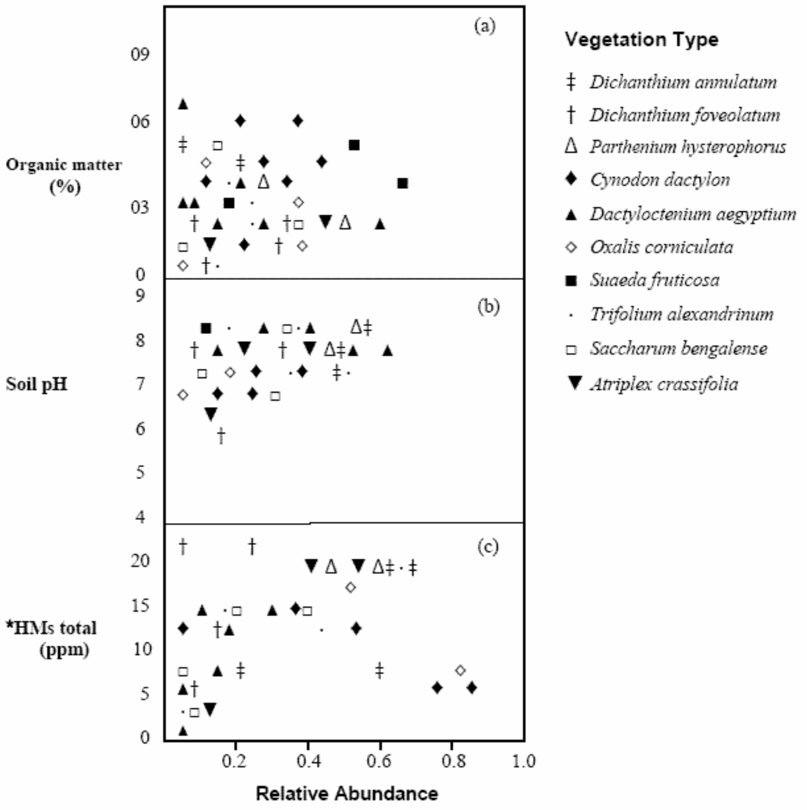

Fig. 2. Relationship between relative abundance: (a) organic matter content of soil, (b) soil pH and (c) heavy metal toxicity level of ordinates. *HM = heavy metals

changing soil pH values (Fig. 2). Both these environmental gradients have shown a functional role in pattern of species distribution. In spite of that, plant responses to heavy metal contents were most indefinite. Majority of species were tolerant for Zn contents but they differ in terms of sensitivity and showed thorough distribution. An identifying role has emerged for persistence of species with regards to heavy metal contents in soil. It also explains how different species in a localized area respond variably in terms of sensitivity. A similar variation in response by native species was observed by Ali *et al*., (2004) in which different metal concentrations in soil influences the phytosociological synthesis.

As a whole the physiognomy of vegetation appeared similar across these stands during the initial survey of area investigated. The vegetation is more open compared to surrounding stands. In the stands 1, 2 and 4, barren patches of soil occur more frequently and vegetation structure especially stratification is reduced. The vegetation composition in these stands indicates that perennial grasses and forbs are more prevalent than shrubs and short-lived annuals. It is too early to suggest any sort of endemic or disjunct species or edaphic ecotypes driven by metal contaminated soil environment that often develop in Pb and Zn-contaminated sites (Kimmerer, 1984). At the same time occurrence of *Atriplex crassifolia* and *Trifolium alexandrinum* in considerable number (14 and 29, respectively at all stands) is a sign of more adaptive or a sort of tolerant behaviour of these species to metals except for lead. Apart from stand 2, where Pb concentration was observed maximum, these two species were less frequently recorded. This shows that although metal toxicity poses some sort of limitation on species persistence and richness, complete devegetation is rare to occur mainly because in general patterns related to soil variations influences local persistence of vegetation (Chytry *et al*., 2003) particularly native species.

Considering the fact that no stand, so far studied is absolutely without ground cover, prediction of threshold limit for heavy metal toxicity would be ambiguous. In addition to that presence of *Suaeda fruticosa* in stand 2 makes the situation slightly different. The species is normally found to exist in saline soil and regarded among halophytes (Waisel, 1972), its presence shows salt tolerance attributes. This accounts for survival of *Suaeda fruticosa* beyond expected or predicted limits as observed for other species. This strengthens the view that it is always intricate to establish a generalized pattern of phytosociological trends if they are to be correlated with environmental factors (Rydgren *et al*., 2003). From an environment management point of view it is desirable to be able to predict the effect on plant community structures of some biotic and abiotic ecological change e.g., restoring natural habitats or pollution from industrial waste. In many cases such ecological predications may be thought of as predictions of the future plant community structure along an environmental gradient (Damgaard, 2003). However, role of gradients is necessarily a focal point in our study. At the same time demonstration of habitat commonness across a gradient in the functional interpretation of vegetation data cannot be ignored (Nygaard & Ejrnæs, 2004) nor any change in species richness due to local and regional environmental conditions can be denied (Schamp *et al*., 2003).

In similar studies like the present one most parameters of the multidimensional environment may in some way influence the outcome of interspecific plant competition interactions, which may affect plant community structures in a foreseeable way (Grime, 2001). Somehow in our study sites, relevance between heavy metal pollution and soil system appeared a complex phenomenon. The first two stands are comparably more metal polluted with few tolerant species. It is probable that interspecific competition was marginal in these harsh conditions where the total coverage of vegetation was low. Competition had more pronounced effect on ecological functioning of plants when the vegetation was closed (Salemaa *et al*., 2001). As a result of which in less polluted stands, species persistence was more prominent and the total coverage was divided more evenly between the species. In conclusion, it appears that accumulation of heavy metals have caused considerable disturbance in the soil ecosystem, altering the succession of plants in such a way that plant invasion and establishment seems difficult. Moreover, further colonization of established species to develop complete stratification or dominance and maximum cover appears restricted. In fact, the species composition of plant communities indicates that sensitive plant species gradually follow a course of decline by forming less coverage. Definitely soil conditions have become unfavourable for them due to metal toxicity that has caused problems in colonization of these species (Gondard *et al*., 2003). Reduced plant cover values further manifest competitive interactions between species. Hence influence of metal contamination on edaphic characteristics is confirmed and the plant dynamics in spatial context is a discrete proof of this at small scale.

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