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Soil Nutrients Can Influence Exotic Species Richness in Urban Areas: A Case Study from the City of Kolkata

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Abstract

Urbanization contributes to extensive land use changes and environmental degradation which may influence changes in soil properties. These abiotic changes may aggravate invasions and favour the distribution and number of invasive species in urban areas which could negatively impact biodiversity. This case study was, therefore, undertaken in the metropolitan city of Kolkata to assess the existing plant species richness (both native and exotic) and to determine the relative role of some soil physico-chemical parameters on species richness. Plant species were recorded and soil samples were collected from each study site. The total species richness ranged from 4 to 25 with 50% of sites having a median number of 11 species. The presence of at least 3 or more invasive species was observed in >80% of sites. The mean and median values of soil parameters showed considerable variation in soil properties between sites. Urban soils had elevated pH values and higher available N, P and Ca. Soil available N appeared to be significantly correlated with both total species and exotic (including invasive) species richness while available phosphorus showed significant correlation with only exotic species richness. The GLM Poisson log-linear models showed a significant positive relationship of soil N with total species richness and exotic richness including invasive species richness in the study area.

Keywords

Urban Area, Species Richness, Soil Physico-Chemical Parameters

1. Introduction

Urban areas, which are rapidly increasing in developing countries like India, not only contribute to the world's population [1] but are also associated with extensive land use changes and environmental degradation [2] [3] [4]. The surface soil in these areas get mixed and is covered by artificial impervious surfaces, due to the mechanical and/or chemical disturbance associated with urbanization, which may cause an irreversible loss of many soil properties and functions [5]. Urban soils contain large pools of carbon, nitrogen and other elements which help to support plant growth and sustain biogeochemical cycles [6]. They also provide an array of ecosystem services like reducing bioavailability of pollutants, habitats for soil and plant biota, microclimate regulation and food production [7] [8] [9]. Hence, any change in soil properties may eventually affect nutrients directly or indirectly endangering soil and plant biodiversity which may eventually lead to environmental changes on a larger scale [10] [11] [12].

The indirect effects of urbanization also involve changes in the biotic and abiotic environment which include the urban heat island effect [13] [14] atmospheric deposition of various pollutants [15] [16] as well as the introduction of exotic species [17]. The rate of atmospheric nitrogen deposition, which has more than doubled over the past century, is one of the main causes of global biodiversity loss and this is especially threatening for tropical regions where the most diverse biota occur [18] [19] [20] [21]. Furthermore, global environmental changes may aggravate plant invasions which have been found to be highly responsive to rising temperature and altered precipitation that may favour the distribution and number of invasive species [22]. Precipitation has been found to be one of the key factors shaping the richness of regional invasive species in India. For example, the richness of naturalized invasive species was found to be positively related to states receiving higher amounts of precipitation [23] while the probable distribution of *Lantana camara* and *Cassia tora* towards northern and north-eastern directions has been demonstrated to be due to changes in moisture availability [24]. The affinity of invasive species towards warmer, drier and wet places was reported in a study by Tripathi *et al.* [25], where a significant correlation of invasive species with anomalies in both temperature as well as precipitation was observed.

In addition to climatic variables which influence plant communities at the regional scale [26], the use of edaphic predictors have also been found to significantly enhance the accuracy of model predictions for plant invasions [27]. Variation in soil properties such as clay content, pH and soil N correlated with a two to four-fold change in the growth of invasive grasses [28]. On the contrary, inconsistent results have also been reported where the physio-chemical properties of soil could not explain the presence of weeds in urban environments [29] while there was no effect of nutrient enrichment on invasion success [30].

With half of the world's population now residing in cities [9], where people and nature coexist in close proximity, the important role of nature in promoting human health and psychological well-being is increasingly being recognized [31] [32] [33]. In view of the rapid pace of urbanization and the continuing decline in biodiversity, it thus becomes important to record the species richness of vegetation as well as the soil physico-chemical properties especially in the developing cities of tropical regions which can act as hubs for spread of exotic species [34]. This study was, therefore, undertaken in the metropolitan city of Kolkata to assess 1) the species richness (both native and exotic) within this area and 2) to determine the relative role of some physico-chemical factors in influencing the existing plant species richness.

2. Materials and Methods

2.1. Study Area

Greater Kolkata is an urban agglomeration of the city of Kolkata, situated in West Bengal, India. It is surrounded by rural areas [35] and is located between 22˚0′19″N to 23˚0′01″ North Latitudes and 88˚0′04″E to 88˚0′33″ East Longitudes, covering an area of 1851 km^2 [36]. The urban built-up land constitutes 54.2% of the current total area and residential use contributes to about 31.2% of the total area [37]. Kolkata has a tropical climate with annual mean temperature of 26.8˚C and monthly mean temperature of 19˚C - 30˚C [37], with high precipitation during the monsoon months (e.g. June to September).

2.2. Sampling Protocol and Estimation of Soil Parameters

Twenty one terrestrial sites, equally distributed on both sides of the Hooghly River, could be sampled for this case study. Within each site, 4 replicates of 1 sq. meter quadrats were randomly placed on a patch of vegetation and species present in the quadrat were noted for estimating species richness. Plants were later identified and the numbers of native species, exotic species and the overall species richness for each site were recorded. Subsequently, soil samples were collected from each quadrat (a composite of 3 subsamples) with a hand held push probe from a depth of 10 cm from the surface, packed in polythene bags and transported to the laboratory for subsequent analysis. In the laboratory, the soil samples were air dried, homogenized using a mortar and pestle, sieved through a 2 mm mesh and stored for further analysis Soil pH and electrical conductivity (EC) were determined using the methods described in AOAC [38]. Available nitrogen (N) content of soil was determined by steam distillation using the Kjeldahl semi-automatic analyzer while available phosphorus (P) was determined by the spectrophotometric method of Olsen *et al.* [39]. The potassium (K) and calcium (Ca) contents were analyzed using the flame photometric method [40]. Soil organic carbon (OC) was analyzed using the dichromate oxidation technique [41].

2.3. Statistical Analysis

The Likelihood Ratio test for equality of means was conducted to examine differences in mean number of richness between native and exotic species distributions. Correlation coefficients were used to assess the strength and direction of the linear relationships between species richness (total species, total exotics, total invasives and total natives) and the soil physico-chemical variables. Transformations were performed when necessary to satisfy assumptions. Generalized linear models (GLMs) with Poisson regression were used, assuming logarithmic relationships (the link function) between explanatory (X) and response variables (Y), to study the relationship between the significant soil parameters and plant species richness. Three Poisson log-linear regression models were used to investigate the effect of soil parameters on species richness.

Model 1 $$Y_1 | X_N \sim \text{Poisson}\left(e^{\alpha+\beta_1 X_N}\right)$$

Model 2 $$Y_2 | X_N, X_P \sim \text{Poisson}\left(e^{\alpha+\beta_1 X_N+\beta_2 X_P}\right)$$

2a $$Y_2 | X_N, X_{\ln P} \sim \text{Poisson}\left(e^{\alpha+\beta_1 X_N+\beta_2 X_{\ln P}}\right)$$

Model 3 $$Y_3 | X_N \sim \text{Poisson}\left(e^{\alpha+\beta_1 X_N}\right)$$

where

Y_1 = No. of total species; Y_2 = No. of total exotics; Y_3 = No. of total invasive; X_N = Soil available nitrogen (mg/kg); X_P = Soil available phosphorus (mg/kg) and $X_{\ln P}$ = Soil available phosphorus – ln transformed (mg/kg).

All the statistical analyses were carried out using R version 3.2.

3. Results and Discussion

3.1. Species Richness in Urban Areas

The overall distribution of species richness from selected sites, provided in Table 1, shows a wide variation in total species richness ranging from 4 to 25 within the city of Kolkata. The median values, which are more robust to outliers than the mean, were 11, 5 and 5 for total species richness, native species and exotic species numbers respectively. When the sites were judged for richness patterns based on the median values, 50% of sites showed total species richness ≥ 11 indicating a good number of species in many urban sites. Similarly, for both native and exotic species, more than 50% of sites supported greater number of species than the observed median value of 5. The Likelihood ratio test revealed no significant difference between mean numbers of native and exotic species richness ($s = 0.214$; $p = 0.643$). Urban areas, with heterogeneous patches of habitats coupled with human introduction of exotic species, often support high numbers of species [15] [42].

Among the exotics, the majority were invasive species (median value of ≥3 in sites) that can spread over long distances from parent plants and can often cause ecosystem damage [43]. The presence of at least 3 or more invasive species in >80% of sites (n = 17/21), as is evident from the table, denotes the presence of multiple invaders in most sites. Urban landscapes are highly altered by development and human activities [7] which is one of the prime reason for the increasing prevalence of exotic plant species (many among which are invasive) that are being reported from cities [44]. Negative impacts of plant invasions on soil

Table 1. Distribution of plant species richness in Kolkata.

		Minimum	Maximum	Mean ± SD	Median	Presence in sites based on median values
Total species richness		4	25	11 ± 4	11	11 (n ≥ 11) 10 (n < 11)
Total native species richness		2	15	6 ± 3	5	15 (n ≥ 5) 6 (n < 5)
Total exotic species richness	All exotics	2	10	5 ± 2	5	12 (n ≥ 5) 10 (n < 5)
	Only Invasives	2	9	4 ± 2	3	17 (n ≥ 3) 4 (n < 3)

properties and processes [45] have been reported from both natural and managed environments [46] [47] [48].

3.2. Urban Soil Physico-Chemical Properties

The artificial surface layer of soil that is distributed in urban area and suburbs is physically disturbed, chemically polluted and spatially heterogeneous since it is highly influenced by anthropogenic activity [9] [49] [50]. Some of the key agents of urbanization that may alter soil physical and biological properties are housing, commerce, traffic, construction and waste, amongst others [51] [52] which result in compacting, crushing and sealing of urban soils [53]. Ecosystem services provided by soil may be severely impacted due to degradation caused by industrial activity [54] while contamination of urban soils by heavy metals may endanger biota as well as human health [55] [56] [57]. However, microorganism habitat and carbon sequestration services may be enhanced in urban soils [6] [58] [59] [60].

The soil physico-chemical parameters determined for the investigated sites are reported in **Table 2** which showed wide variation between sites. Soil pH ranged from 6.6 to 9.4 with 90% of sites having alkaline pH. Urban soils with elevated pH values have been widely reported [10] [50] [61] [62] which could mainly be related to the release of alkaline leachates from calcareous materials in cement, concrete, mortar, and atmospheric particulate deposition [63] [64]. Soil pH can influence many soil chemical processes that determine the behaviour of nutrients and contaminants which can thereby influence availability of nutrients for plant growth [65]. For example, changes in soil pH can influence the critical concentrations of heavy metal toxicity in both plants and microorganisms [66]. Conductivity, which is a measure of ions present in solution, varied from 39.3 µs to 1151.7 µs among the sites.

The soil organic carbon content is a key constituent that dictates the soil physical and nutrient status e.g., water holding capacity and storage of nutrients (mainly N). Values of organic carbon ranged from 4.87 g/kg to 26.22 g/kg in the

Table 2. Analysis of soil physico-chemical properties in Kolkata (n = 21).

	Minimum	Maximum	Mean ± SD	Median	CV%
pH	6.6	9.4	7.9 ± 0.6	7.9	8.1
Conductivity (μs)	39.3	1151.7	346.7 ± 329.5	216.0	95.0
Organic Carbon (g/kg)	4.87	26.22	11.98 ± 6.37	10.13	53.12
Available N (mg/kg)	64.03	214.42	121.76 ± 34.55	113.31	28.38
Available P (mg/kg)	11.38	337.87	131.76 ± 93.05	109.49	70.62
K (mg/kg)	63.72	493.03	207.76 ± 133.17	144.97	64.10
Ca (mg/kg)	1218.4	3450.8	2363.6 ± 578.8	2412.9	24.5

studied sites. Higher values (40.08 g/kg) of soil organic carbon have been reported from industrial sites while lower values (8.24 g/kg) were found in suburban areas [6] [67]. Reduced carbon pool in microbial biomass due to soil compaction and decreased fertility of soils under heavy metal contamination are some of the factors that can prevent carbon accumulation in soil while enrichment may occur as a result of high carbon dioxide content in air, greater productivity of vegetation due to elevated temperature and reduced mineralization of plant residues under the influence of contamination with heavy metals [6] [62]. Soil contamination with coal waste is a problem in many Asian countries. Even in metropolitan cities in India, the majority of poor households continue to use cheap solid fuels like coal or charcoal [68] which may contaminate the soil.

The range values of available N, P and K in soil samples within the investigated area were similar to those reported from other urban areas [61], although the mean available N (121.76 mg/kg) and P (131.76 mg/kg) were relatively higher. Soil nutrient contents were reported to be higher in urban areas [69] and a significantly higher P and K concentrations were observed in soils from industrial and residential city areas as compared to those from urban unmanaged forests [10]. Industrial activity and motor vehicles also release reactive nitrogen to the atmosphere through the combustion of fossil fuels and other processes to form nitrous oxides [19] which subsequently get transferred to the soil surface either as dry or wet depositions [70]. Pollutants from untreated sewage, domestic waste and excessive fertilizer applications could all contribute to N and P accumulation in urban and suburban soils [71] [72]. Furthermore, urban soil nitrogen and phosphorus can be desorbed from soils and excessive environmental inputs can cause freshwater eutrophication [73] [74]. As essential nutrients for biota, the levels of N, P and K in urban soils have implications for urban plant growth. High phosphorus appeared to inhibit species richness while intermediate levels of potassium appeared beneficial to diversity levels in a study on the relationships between species diversity and soil conditions in two created urban meadows sites [75]. All sites exhibited high levels of the secondary nutrient Ca, ranging from 1218.4 to 3450.8 mg/kg, which were similar to those reported in China [61]. Ca is a major component of urban construction materials (*i.e.*, cement and concrete) and high levels of Ca near roadside and residential areas increases the level of extractive K which is further catalysed by high soil pH [61].

Compacted and polluted soils, resulting from construction and infrastructure development of urban landscapes [51], could also influence the soil organic matter pool which has a faster turnover rate due to a much reduced mean residence time (5 years) in moist tropical areas compared to 9 - 14 years in temperate regions [76]. Changes in soil organic content may affect microbial activity in soil which is a key component of soil fertility [77]. Under urban conditions, the biogeochemical cycles of C and N are also affected [78] [79]. All this could influence the variation in nutrient content observed not only in urban and suburban soils [80] but also within different sites in urban areas [67].

3.3. Soil Physico-Chemical Properties and Species Richness

Soil physiochemical properties may affect plants directly through modification of biomass [81] [82] or indirectly through microbial community structure [83] [84]. All these, in turn, may induce changes in organic matter decomposition and other soil processes, and thus, in concentrations of total and available nutrients in soil [85]. Correlation coefficients, which reflect the linear relationship between the physicochemical properties of soil and plant species richness (total, native and exotics), were hence computed and have been reported in **Table 3**. Available N was significantly correlated with total species and exotic (including invasive) species richness while available phosphorus showed significant correlation with only exotic species richness, though not with invasive species richness. Both nitrogen and phosphorus enrichment are known to impact plant diversity globally since growth of plants in terrestrial ecosystems is often limited by the availability of N or P [86] [87] [88]. Increased soil N depositions can affect plants due to changes in pH and nutrient supply ratios [89] while soil P can also limit primary production of individual plants by limiting elements to terrestrial vegetation and can play an essential role in plant community assembly [90].

The GLM Poisson log-linear models provided in **Table 4** show a significant positive relationship of soil N with total species richness (Model 1, $z = 0.006$, $p = 0.002$), exotic richness (Model 2, $z = 0.033$, $p = 0.013$) as well as with invasive species richness (Model 3, $z = 0.035$, $p = 0.002$). Soil P showed a significant relationship only with exotic richness for natural logarithms of P, as shown in Model 2a ($z = 0.982$, $p = 0.040$). Previous studies have shown that exotic plants have benefitted more than native species with enhanced soil nutrients (mainly N) in different ecosystems [91] [92] [93] [94] [95]. Soil N also appeared to be the most important predictor variable responsible for promoting species richness in this rapidly urbanizing study area.

It has been shown that alterations mediated by invasive exotic plants on soil N cycles have helped these highly competitive species maximize their invasiveness [96] [97] [98] [99] [100]. For example, the ability of plants to alter N cycles within ecosystems and rapidly uptake N has been reported for cheat grass (*Bromus tectorum* L.), one of the most significant plant invaders in western US [101]

Table 3. Pearson's correlation between physico-chemical properties of soil and plant species richness.

Soil physico-chemical parameters	Total species richness		Total native species richness		Total exotic species richness			
					All exotics		Only invasives	
	R	*p*	*R*	*p*	*R*	*p*	*R*	*p*
pH	−0.263	0.250	−0.308	0.175	−0.134	0.564	−0.094	0.685
Conductivity (µs)	−0.369	0.100	−0.363	0.106	−0.277	0.225	−0.165	0.476
Organic Carbon (g/kg)	0.090	0.700	−0.071	0.761	0.269	0.238	0.182	0.430
Available N (mg/kg)	**0.509***	**0.019**	0.325	0.150	**0.604****	**0.004**	**0.637****	**0.002**
Available P (mg/kg)	0.336	0.136	0.184	0.424	**0.438***	**0.047**	0.359	0.110
K (mg/kg)	−0.123	0.595	−0.258	0.259	0.083	0.721	0.028	0.905
Ca (mg/kg)	−184	0.424	0.259	0.257	0.039	0.867	0.101	0.664

R: coefficient of correlation; *p*: significance; $^{*}p < 0.05$; $^{**}p < 0.01$.

Table 4. Coefficient estimates and significance results from log-linear Poisson regression analysis using GLM for number of total species and invasive species in relation to soil nitrogen (Model 1 and 3) as well as for numbers of exotic species in relation to soil nitrogen and phosphorus (Model 2 and Model 2a).

	Response variables	Predictor variables	Estimate (z)	Std. Error	t value	Pr(>|t|)
Model 1	Total species richness	Intercept	1.864	0.278	6.719	**1.83e−11*****
		Nitrogen	0.006	0.002	3.037	**0.002****
Model 2	Total exotic richness	Intercept	0.128	1.419	0.090	0.929
		Nitrogen	0.033	0.012	2.769	**0.013***
		Phosphorus	0.006	0.004	1.480	0.1561
Model 2a	Total exotic richness	Intercept	−3.129	2.046	−1.529	0.1437
		Nitrogen	0.029	0.011	2.623	**0.0173***
		Ln Phosphorus	0.982	0.444	2.212	0.040*
Model 3	Invasive species richness	Intercept	−0.362	1.214	−0.299	0.768
		Nitrogen	0.035	0.009	3.606	**0.002****

Model significant at $^{*}p < 0.05$ level.

as well as for *W. trilobata* for its successful invasion in China [102]. Some broad-scale studies have also found positive relation between spatial patterns of cheat grass abundance and levels of soil P [103]. Environmental variability in soil nutrient availability (as a consequence of increased fluctuations in extreme events e.g. flooding, droughts, heat waves, fires) was found to strongly promote the invasion success of the Japanese knotweed (*Fallopia* spp.) and possibly of many other invasive plants [104].

Increased soil N availability can lead to enhanced biomass production by invasive plants which can affect their growth and competitive advantage over natives due to the higher resource acquisition and lower nutrient requirements of the invaders [105], thereby intensifying invasions [106]. The invasive biomass differs from the native biomass in chemical quality e.g. lignin and nutrient content, C/N and lignin N ratios and/or secondary metabolites [107] [108] [109]. Sites with invasive plants can affect soil processes through root exudases and enhanced rates of litter decomposition, a process mediated by the soil microbial community, thereby accelerating nutrient cycling and the subsequent release of available N and P into soils [110] [111] [112]. The growth rate (RGR) of *Rumex confertus*, another invasive species, was also found to increase with increasing nutrient (N, P, K) supply [113].

Changes in soil properties brought about by plant invasions can be problematic as they may lead to feedbacks that stabilize or accelerate further invasion [85]. There still continues to be an increased availability of N from various urban contaminant sources and atmospheric nitrogen depositions which is a major environmental change factor [19]. Moreover, N has been suggested to be an important limiting factor to fast growing invasive species including week invaders [114] which could possibly be the reason for the presence of multiple invasive species that are being increasingly reported from urban areas [115] [116].

The processes influencing urban plant species patterns are highly complex ranging from soil compaction, pollution, habitat fragmentation, high disturbance regimes along with the changing climatic factors. Since biodiversity in urban and suburban areas can decline either due to habitat transformation or landscape fragmentation, vegetation can be an important indicator of urbanization pressure on biodiversity in cities. Thus, surveys aimed at investigating floristic diversity in cities of tropical areas could be useful for understanding the present ecological changes in order to undertake effective management procedures to make cities ecologically and socially sustainable.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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