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Impact of Spatio-temporal Variation in Plant Communities on Different Soil Chemical Properties in Yamuna Biodiversity Park, Delhi, India

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Abstract
Yamuna Biodiversity Park which located in semi-arid region of Delhi has a problem of soil salinity. The park has applied both phytodesalination and phytoremediation techniques to reclaim its saline soil. Many types of plants have been introduced and reintroduced to reduce the soil pH and salinity and to restore its nutrient content. The purpose of the work was to study the impact of spatio-temporal variation in plant communities on soil chemical properties. The vegetation sampling was conducted by selecting fifteen sampling plots sized 10×10 m^2 to measure density, diversity, richness and abundance of plant species including trees, saplings and grasses and to measure girth at breast height of trees sized above 20 cm. Soil sampling was carried out using appropriate methods and equipments to measure soil temperature, moisture content, pH, salinity, electrical conductivity (EC), organic matter, nitrate and phosphate content. Results showed an inverse correlation between soil pH and sapling and grass density, while salinity and EC values were inversely correlated with plant diversity and species richness. Inverse correlation was also seen between soil organic matter and pH. Meanwhile, direct proportional relationship was found between soil nitrate and plant diversity and density, and between soil phosphate and plant diversity. Comparison to the earlier data gave spatio-temporal variation. Results showed many improvements in soil chemical properties during five-year period including soil pH, salinity, EC and soil nutrients including organic matter, nitrate and phosphate contents. This proved that phytoremediation technique by introduction/reintroduction of plant species has succeeded to reclaim the degraded saline soils and to restore soil nutrients.

Keywords: bioreclamation, phytoremediation, plant reintroduction, soil restoration, soil salinity

1. Introduction

Land degradation is a major factor constraining world food production, and land salinization is large component of that degradation (Mishra *et al.*, 2003) [12]. The United Nations Environment Programme estimates that approximately 20% of agricultural land and 50% of cropland in the world is salt stressed. Salinisation is one of the most serious problems confronting sustainable agriculture in irrigated production systems in semi-arid and arid regions. In India, about 30 million ha of coastal land remains barren and uncultivable because of bad soil affected by salinity (Ravindran*et al.*, 2007) [19].

Numerous physical (e.g. tillage and drip irrigation) (Sadiq *et al.*, 2007; Tan & Kang, 2009) [20, 22], chemical (e.g. sulfuric acid and gypsum) (Sadiq *et al.*, 2007; Qadir*et al.*, 1996) [20, 16] and biological approaches were established to reclaim such soils (Rabhi*et al.*, 2010) [18]. Biological methods include the use of green manure, mulch, earthworms, vermiwash, and vermicompost (Ansari, 2008) [2], crop rotation, salt-tolerant crops, halophytes (Keiffer&Ungar, 2002; Ravindran*et al.*, 2002) [8, 19], mycorrhizal and rhizobial inoculation as well as bioreclamation (Helalia*et al.*, 1992) [7]. The latter is also called bioremediation (Al-Abed *et al.*, 2004; Ansari, 2008; Badi&Sorooshzadeh, 2011) [1, 2, 3], vegetative bioremediation (Qadir& Oster, 2002) [17], phytoremediation (Qadir*et. al*,2001, 2005) [15, 14], biorejuvenation (Mishra *et al.*, 2003) [12], biodesalination and phytodesalination (Rabhi*et al.*, 2010) [18].

Yamuna Biodiversity Park (YBP) which lies on the Khadar area of Yamuna flood plain in the semi-arid region of Delhi also has problem in soil salinity. When the park first developed in 2002, the soil was found to be highly saline. The land was covered by a crust of salt deposition on its surface. This sodic characteristic of the soil that revealed to have pH of up to 9.8 makes it extremely difficult for the wild plant species to survive (Saha, 2006) [21]. The problem of this saline-sodic soil has forced many scientists to work hard on bringing down the pH of the soil without using any chemicals.

YBP has applied both phytodesalination and phyto-remediation techniques to reclaim its sodic soil. Many types of plants, initially grasses and legumes, have been introduced to the park to reduce the soil pH and salinity and to enrich its nutrient content, so other sensitive plants can also share the habitats. Legume plants such as Subabool (*Leucaena leuco-cephala*), *Sesbania aegyptica*and *Sesbania sesban* are some of the examples. The more improvement of soil quality, the more number of plant species can grow and survive in the park. Presently, after almost 8 years operation, the plant communities in YBP have increased remarkably due to suitable condition of soil nutrients required for plant growth.

The aim of this study is to investigate the impact of spatio-temporal variation in plant communities on different soil chemical properties. The soil properties also include some of physical parameters, such as temperature and soil moisture, as well as the mineral and nutrient content of the soil. The study also intends to see how floral diversity grows at different types of soil across the designated habitats by developing the information about the growth, maturity, density and diversity of plant species. To achieve that, following objectives have been laid down: (i) vegetation analysis across the designated plant communities; (ii) soil property analysis across the habitats; and (iii) comparison of present condition of both plant diversity and soil characteristics with the earlier condition described in any available secondary data.

2. Study Area

Study was conducted in Yamuna Biodiversity Park, which is located in the region of Delhi, extended from 28º25’N to 28º53’N and 76º50’E to 77º22’E. The park itself is located at 28º44’N and 77º12’E on northern part of Delhi, specifically in Jharoda Majra Burari, near Jagatpur village, Wazirabad on western side of River Yamuna. Therefore, this park was originally a floodplain area and often experienced flooding in every monsoon season at about 3-4 decades ago.

Yamuna Biodiversity Park is located an elevation of 682 ft above sea level and spread over an area of 437 acres. Of all forests and communities provided in YBP, five sites were selected as sampling locations among designated biotic communities. Two plots were in the Visitor Area and the remaining three were in Conservation or Nature Reserve Area (Figure 1). All sites in both areas are protected and managed by joint-collaboration project between Delhi Development Authority (DDA) and the Centre for Environmental Management of Degraded Ecosystems (CEMDE), University of Delhi (Niangthianhoi and Khudsar, 2009) [13]. Most of the plots in Visitor Area were mounds with small area.

The geographical locations of the plots are:

VA1: 28º 43' 55.8" N 77º 13' 07.9" E
VA2: 28º 43' 47.5" N 77º 13'08.2" E
HC: 28º 43' 58.2" N 77º 12' 55.6" E
TC: 28º 44' 05.9" N 77º 12' 52.9" E
SC: 28º 44' 16.7" N 77º 12' 53.2" E

3. Materials and Methods

There are mainly two basic methods used in this study: vegetation and soil sampling methods. For vegetation analysis, stratified random sampling method was used to assess plant diversity, density, and species abundance (Michael, 1984) [11]. In stratified random sampling (Kent & Coker, 1992) [9], a number of permanent plots sized 10×10 m^2 have been constructed in different habitat types, and geographical location of each sampling points were recorded using Global Positioning System (GPS) at the centre of the plots. Within these plots, number of tree species, saplings, and grasses were counted and attempts were made to measure girth at breast height (GBH) of tree trunks bigger than 20 cm (Khudsar, 2010) [10].

Soil samples were collected from the same plots with that of vegetation sampling by using soil auger, stored in a number of sealed plastic pouches and taken to laboratory for further chemical analysis. Soil temperature was directly measured using specific thermometer for soil analysis at the same time with that of soil collection. Soil pH, salinity and electrical conductivity were measured by direct reading of some specific digital pocket instruments after dissolving and filtering the soil in some amount of water. Soil moisture content was determined using gravimetric method (oven-drying method), while organic matter was estimated using Walkey-Black method (Michael, 1984) [11]. To estimate nitrate and phosphate content of the soil, combination method was performed that included chemical preparation, filtration and direct reading of portable instruments (Carter, 1993) [5].

4. Results and Discussion

Vegetation richness has been rapidly increasing in YBP. Number of plant species found in all communities has been continuously added and introduced every year by either plantation or natural regeneration (i.e. by animals, wind or water flows). The forests are now remarkably denser as compared to the earlier stages of development. The rapid change was not only in the density, but the diversity of the forests has also increased.

Plant diversity was measured using Shannon-Wiener Index (H'). Result showed that Teak Community has the highest plant diversity as compared to other plant communities, while Hardwickia Community performed as the least diverse (Table 1). Species richness represents number of plant species occurred in each plot. Each species may be found as only one individual or more. Of 5 plots studied in Yamuna Biodiversity Park, Teak Community and Sal Community both have the largest species richness with 28 plant species, and again Hardwickia Community has the lowest species richness with only 11 plant species occurred (Table 1).

High number of species, or species richness, found in one location does not always indicate high number of diversity. High diversity forest can also be found in forests with low species richness. VA2 which has lower species richness as compared to SC was found to have higher diversity index. The distribution factor of the plants was the reason for this problem. Plants in VA2 were distributed almost equal number to each species, while in SC one species of plant has dominated the site making the distribution to be unequal.

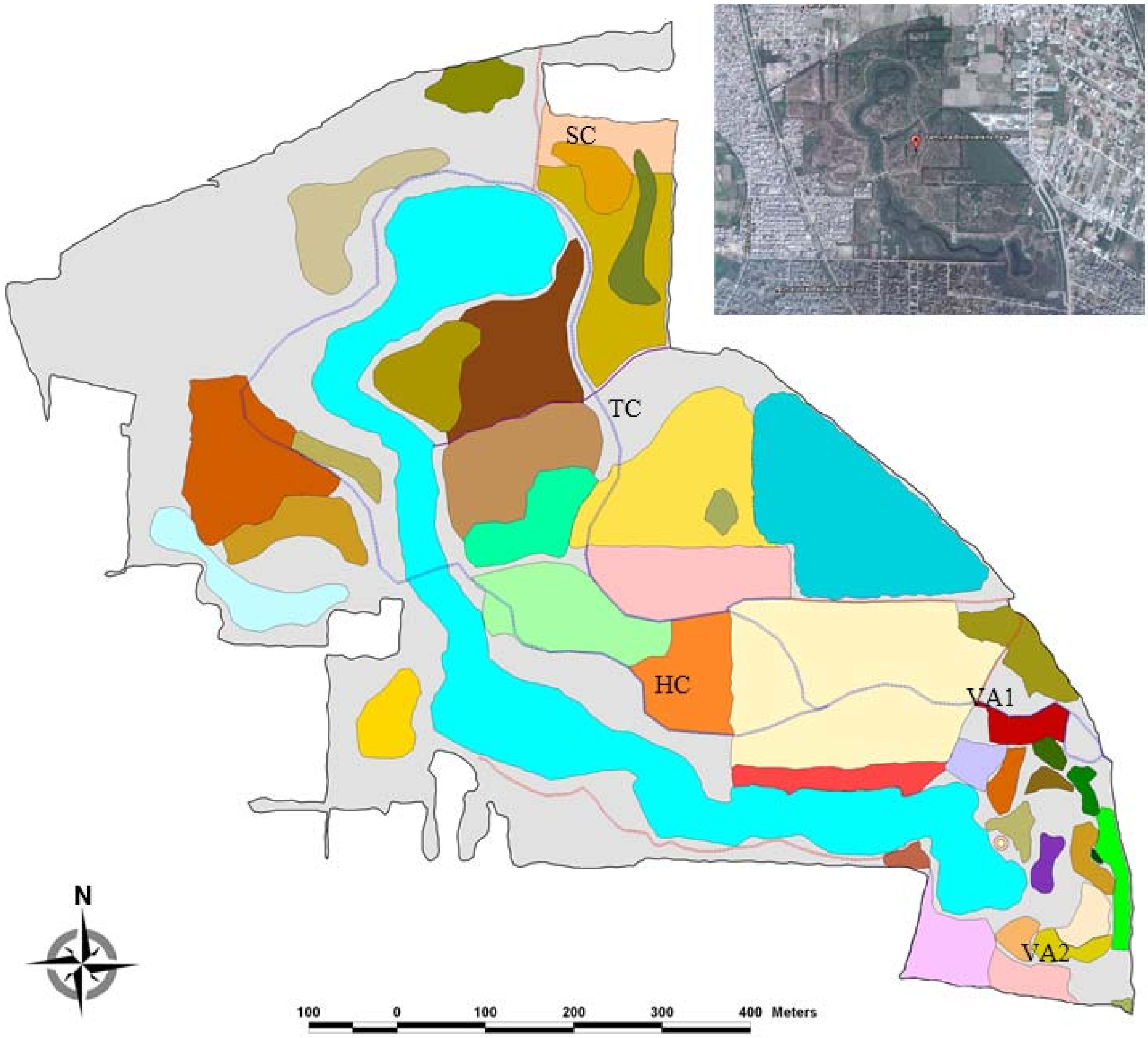

Fig 1: Map of Yamuna Biodiversity Park showing location of 5 sampling sites. VA1=Visitor Area 1 (Mixed deciduous forest), VA2=Visitor Area 2 (Tropical dry deciduous forest with teak), HC=Hardwickia Community, TC=Teak Community and SC=Sal Community (Inset: Aerial view of Yamuna Biodiversity Park).

Table 1: Distribution of vegetation and soil chemical properties in different sampling plots in 2011.

Plant Communities	VA1	VA2	HC	TC	SC
Vegetation profiles					
Shannon-Wiener Index (H’)	1.33	1.55	1.08	1.69	1.38
Species richness	14	20	11	28	28
Plant density, per 100 m^2	85	396	579	679	1094
Tree density, per 100 m^2	7	16	3	7	11
Sapling density, per 100 m^2	20	362	326	509	783
Grass density, per 100 m^2	58	18	250	163	300
Mean GBH, cm	52.9	42.7	37.7	34.0	31.3
Soil chemical properties					
Temperature, ºC	32.0 ± 0.5	39.3 ± 2.1	39.5 ± 1.3	34.2 ± 1.8	30.8 ± 1.3
Moisture content, %	7.9 ± 1.7	1.8 ± 0.8	19.8 ± 3.4	23.3 ± 1.0	17.5 ± 3.7
pH	7.47 ± 0.22	7.61 ± 0.12	7.19 ± 0.18	7.37 ± 0.10	7.41 ± 0.09
Salinity, ppt	0.13 ± 0.06	0.00 ± 0.00	1.73 ± 0.12	0.40 ± 0.10	0.23 ± 0.06
Electrical Conductivity, µS/cm	247 ± 125	91 ± 24	1694 ± 166	688 ± 226	403 ± 106
Nitrate-N, mg/100g	3.4 ± 2.5	4.1 ± 2.5	3.5 ± 3.0	3.6 ± 3.5	3.9 ± 3.4
Phosphate-P, mg/100g	30.2 ± 21.8	19.5 ± 6.1	19.3 ± 9.5	19.3 ± 4.8	21.9 ± 2.1

VA1=Visitor Area 1 (Mixed deciduous forest), VA2=Visitor Area 2 (Tropical dry deciduous forest with teak), HC=Hardwickia Community, TC=Teak Community, and SC=Sal Community.

Plant density was counted in three categories: tree, sapling and grass density. Tree density is often less than sapling or grass density. It was also observed that the majority of tree species (80%) were having girth 20-50 cm. Among all plots studied, VA2 has the largest tree density, and the lowest tree density was again found in Hardwickia Community.

Density of forests does not only determine the quality of the environment they have, but it also determine the maturity of the forests. The forest maturity can be exactly estimated by looking at tree rings, but it is not exactly wise thing to do as the trees have to be cut down first to count how many tree rings are there. Another simple, but not exact, estimation is by measuring girth at breast height (GBH) that have also been conducted in this study. VA1 was found to have more number of thick trees, as they have more mean GBH value than other forests. Conversely, SC has the least number of thick trees, because most of the trees found there were young and less than 20 cm GBH. Therefore, VA1 was identified as the most mature forest among other forests inside the plot. Though VA2 has higher plant density, but forest in VA1 was assumed to establish earlier than all other forests. So, most of the trees there were estimated older in age. But, overall, forests in YBP are young; only 20% of all trees were found to have GBH more than 50 cm at all sampling plots, the rests have 20-50 cm GBH, because the fact is that plantation in the park has been started since 2004 (Saha, 2006) [21].

The parameter of GBH was found to be inversely proportional to the number of total plant density. Forests with high mean GBH (more large trees) usually have lesser density than forests with low mean GBH (more small trees). This also indicates the maturity of the forests. Forests that have reached their maturity stage would have lesser density than immature forests, because immature forests have more empty basal area that allowing new seedlings to grow hence make the forest denser. Therefore, density of forest in YBP was not actually governed by large number of tree species. Number of saplings including small trees, shrubs, herbs, seedlings and climbers affected the density and the basal cover of the site more. But most of the saplings, particularly herbs, were categorized as annually-growing species that were abundant only in a particular season. Thus, they cannot identify the maturity or density of the forest as they may disappear in the next non-growing season.

The chemical properties of the soil can alter the characteristics of vegetation grow in a particular area and vice versa. Many plant species require specific soil and climatic conditions to grow till they reach their maturity stage and these criteria might vary to different type of vegetation. Soil properties would also change by alteration of specific plant species and microorganisms live there either independently or symbiotically with the plants. Some properties were highly alterable and some of them were not.

Soil temperature exhibits almost similar state between all forests in YBP. There was no significant difference between each other. Most of the temperature ranged from 30 to 40ºC (Table 1). The difference may be found if the measurement were conducted in different season such as winter and summer, as shown in Table 2. This depends mostly on the climate of the city of Delhi, which is located above the Tropic Cancer, and the season when the measurement takes place.

However, the study found that HC has the highest soil temperature among others. It might be due to this community has smaller number of big trees or less tree density. By their wide canopies big trees helped to cover soil surfaces and to protect the soil from hot radiation of sunlight at daytime. VA2 also showed high soil temperature due to the site is a mound as compared to other sites which are plain areas.

Soil moisture content hardly depends on water content in the soil. High soil moisture content indicates that the soil has two main characteristics: (i) more water washing either from precipitation or from water flooding of neighbouring water bodies, and (ii) less water evaporation from soil due to high cover of land by relatively dense vegetation. All plots in Conservation Zone have more soil moisture content than forests in Visitor Zone.

The amount of water in the soil was mostly influenced by the quantity of precipitation occurred in that area. Therefore, soil moisture content would be higher in monsoon season. The difference in selection of sampling time sometimes created an error on the soil study and made the data incomparable. Therefore, measurement of soil moisture content is highly advisable to include all conditions in every season.

Acidity, or pH, salinity and conductivity of the soil highly affect plant growth. Some plants have their pH preferences for their growth. Soil that has pH lower or higher than these requirements will not serve as good habitats for some specific plants. On the other hand, plants can also slowly alter soil conditions to meet their preferences. Soil pH, salinity and conductivity can change by time during plants grow in that particular area. The process needs time, may be years or so, to meet suitable conditions that plants require. This is one example of soil remediation process, which is often called as phytoremediation.

In general, most of sites in YBP have recovered their soil pH from saline to neutral. All the remaining plots now have relatively neutral pH ranged from 7.1 to 7.6 (Table 1). The decline in soil pH during this period of time was due to the

Table 2: Comparison of soil properties in different communities between summer and winter 2011.

Soil Parameter	Summer				Winter			
	VA	HC	TC	SC	VA	HC	TC	SC
Temperature, ºC	35.7	39.5	34.2	30.8	18.0	25.3	21.6	21.4
Moisture content, %	4.9	19.8	23.3	17.5	12.8	26.0	25.0	19.2
pH	7.54	7.19	7.37	7.41	7.34	6.82	7.06	7.20
Salinity, ppt	0.07	1.73	0.40	0.23	0.05	1.10	0.40	0.20
EC, µS/cm	169	1694	688	403	178	1571	1046	481
Nitrate-N, mg/100g	3.8	3.5	3.6	3.9	9.5	3.7	10.3	4.1
Phosphate-P, mg/100g	24.8	19.3	19.3	21.9	10.4	3.6	7.2	5.6

VA=Visitor Area, HC=Hardwickia Community, TC=Teak Community, and SC=Sal Community.

act of plants and soil microbes that help to degrade plant litter and convert it into humic acid (or later into humus) and, hence, slowly decline soil pH.

Soil salinity was measured in ppt unit. It indicates the amount of salts contained in the soil. High amount of salts can be identified by clear white deposition presented in the soil surface. All forests in Visitor Area have low salinity profiles. The salinity in VA2 was even untraceable to ppt unit. HC showed high content of salinity (Table 1). This was due to the site is low-land area and sometimes experienced flooding from water bodies or from precipitation run-off fallen from neighbouring high-land areas or mounds.

Salinity of the soils influenced the diversity and richness of plant communities and vice versa. Besides having the highest salinity, HC has also the lowest diversity. Therefore, the relation between soil salinity and plant diversity was found to be inversely proportional.

The parameters of soil salinity and conductivity were found to be closely related each other, because both parameters refer to the amount of ions present in the soils. The result showed similar profiles between these two parameters. It showed relatively low electrical conductivity (EC) values in all plots located in Visitor Area as compared to plots in Nature Reserve Area. It may be due to sites and mounds in Visitor Area were mostly man-made sites and have experienced higher degree of tillage and soil hoarding, hence more-saline surface soil and less-saline deep soil were mixed well.

Comparison between EC values and vegetation profiles (plant diversity and species richness) showed an inversely proportional relationship, similar to salinity. The reason for this similarity between salinity and EC was that the parameters were both influenced by the amount of free ions contained in the soils, mostly Na^+ and Cl^- ions (Carter, 1993) [5]. Therefore, they have direct proportional relationship between each other.

In general, phosphate-P content in YBP's soil was almost same to all sites. Plots in VA1 performed as the highest phosphate-P content among others (Table 1) due to VA1 is low-land area and it has high amount of phosphate taken from fertilizer run-off from its surrounding high-land area or mounds that had been washed away by precipitation.

Shannon-Wiener Index, an index for measuring plant diversity, showed a variation in the result. In 2011 vegetation sampling, some communities (VA and TC) showed an increase profile from 2006 to 2011, while the remaining communities (HC and SC) performed a declining figure (Table 3).

Increase in Shannon-Wiener Index indicated that the forests were more heterogeneous, while forests which have a decline in Shannon-Wiener Index were closer to homogeneity.

Plant density profiles of six different plant communities studied in YBP showed a rise pattern from 2006 to 2011 (Table 3). The highest increase of plant density during this five year periods was found in plots in Nature Reserve Area rather than in Visitor Area. The difference was due to the maturity of the sites. Therefore, they might have great increase in plant density, especially sapling density. But this still depended on how good were soil conditions and how many nutrients were available in that site.

Soil temperature can alter plant growth, especially at seedling stage. In this study plant density was found to have effect on soil surface temperatures. Tree's canopy has the ability to cover and cool the soil surface. But, in general, soil temperature was mostly affected by climate and seasonal variation of the forests through the year. Therefore, soil temperature was found to be lower in winter rather than in summer season (Table 2).

Similarly, soil moisture was also affected mostly by weather and seasonal conditions. Even though the evaporation of soil moisture can be prevented by plants' cover, the effect of air temperature and the duration of sunlight during particular season influenced more. That is why soil moisture in summer was less than in winter because of high sunlight evaporation (Table 2). However, it was found that soils collected in summer 2006 has less moisture content than soils collected in summer 2011 (Table 3). This was due to high improvement in plant density and plant cover.

The soil in Yamuna Biodiversity Park at early stage of its development has higher pH, salinity and conductivity that was not preferable for most of the plants. The pH value of soil in YBP earlier was very high. In 2002 soil pH has reached 9.8 makes it very difficult for the plants to survive (Saha, 2006) [21]. As the time goes by, some specific plants were introduced, especially ones that having salt tolerant characteristics. More and more plants were then planted there as well as the native species of Yamuna river basin were also reintroduced. Introducing number of plants species helped the soil to recover and to decrease the pH to become more suitable to all plant species, hence the plant diversity of the

Table 3: Comparison of vegetation and soil profiles in different communities in 2006 and 2011.

Parameter	2006*				2011			
	VA	**HC**	**TC**	**SC**	**VA**	**HC**	**TC**	**SC**
Vegetation profiles								
Shannon-Wiener Index (H')	1.63	1.11	0.56	1.52	2.00	1.08	1.69	1.38
Species richness	29	14	16	29	25	11	28	28
Plant density, per 100m^2	168	470	176	678	317	579	679	1094
Soil chemistry profiles								
Temperature	34.5	38.5	36.8	34.5	35.7	39.5	34.2	30.8
Moisture content, %	0.3	11.6	13.3	13.2	4.9	19.8	23.3	17.5
pH	7.4	7.0	7.1	7.4	7.54	7.19	7.37	7.41
Salinity, ppt	0.25	1.30	1.15	0.20	0.07	1.73	0.40	0.23
EC, µS/cm	450	2200	1800	300	169	1694	688	403
Nitrate-N, mg/100g	4.4	1.8	10.0	2.2	3.8	3.5	3.6	3.9
Phosphate-P, mg/100g	3.7	2.5	5.7	1.3	24.8	19.3	19.3	21.9

VA=Visitor Area, HC=Hardwickia Community, TC=Teak Community, and SC=Sal Community. *based on the study of Saha (2006).

area were increasing through the year. Till 2006, more enhancement of soil pH can be revealed. Many areas or habitats then reached pH values between 7.0-7.5.

Among six habitats studied, Teak Community (TC) has high decline in soil salinity. This correlates the facts that this plant community has high increase in plant diversity and species richness. The important concern of soil parameter in YBP was the pH, salinity and electrical conductivity. Soil characteristics changed significantly in YBP by the times and years of its development. In general,

most of the sites in YBP showed declining trends in soil pH, salinity and conductivity from 2006 to 2011. The more distinctive feature was found in soil EC. The change in soil EC profiles in TC within this five year period was relatively significant as compared to the changes found in other plant communities (Table 3).

Hardwickia Community (HC) was found to have experience in a long nitrogen deficiency through the year. It has the smallest nitrate content since 2006 and still became the smallest in 2011. The increase in nitrate (which refers to the increase in nitrogen) content in this site was very slow and needs more efforts from human intervention to help the plants to gain more nitrogen sources.

Phosphorus is also the major nutrient required for plants. In laboratory analysis, phosphorus is calculated as the percentage of available phosphate ions (PO_4^{3-}) or phosphate-phosphorus (PO_4-P). The content of phosphate-P in YBP's soil increased from 2006 to 2011 in all sites. This was due to high plant density and it affected the chemical properties of soil, particularly the available phosphorus.

Overall, increase in nitrogen and phosphorus content in soils resulted in the increase in plant density as well as plant diversity. These N and P parameters were both important in soil study, particularly for soil reclamation and restoration purposes, because increase in these two parameters, together with potassium or K parameter, indicates enhancement of soil nutrients and fertility (Tárrega*et al*., 2007; Foth, 1990; Brady, 2000) [23, 6, 4].

5. Conclusion

The important findings in the analysis were the correlation between vegetation profiles and soil chemical properties. The correlation between soil pH and sapling and grass density was clearly found in this work. Plot with highest soil pH (7.9) was found to have less sapling and grass density, whereas plot with highest sapling and grass density was found to have very suitable pH (7.01). Results also showed correlation between soil salinity and electrical conductivity (EC) with plant diversity and species richness, in which plots with highest salinity and EC values were found to have lowest diversity and richness.

Soil organic matter was found to have correlation with soil pH, in which plots with high soil pH has lesser organic content as compared to plots with lesser (neutral) pH value. The correlation between soil nitrate-N with plant diversity and density was also found. Having higher nitrate-N content, some plots were found to have higher plant density and diversity, and low nitrate-N resulted in low diversity and density. Direct proportional relationship was also found between soil phosphate-P content and plant diversity. Plots with higher phosphate-P content were found to have higher diversity index, and vice versa.

The data were also compared with a secondary data from 2006 study (Saha, 2006) [21]. The comparative spatio-temporal results obtained showed that there were many improvements in soil chemical properties from 2006 to 2011. Soil pH, salinity and EC have gone down during this five year period. Highly saline and sodic soils that mostly found in early development of the park are now improving to be more neutral and suitable for plant growth. Soil nutrients, including organic matter, nitrate and phosphate content, have been significantly increasing to certain values better than few years ago. This proved that introduction/reintroduction of plant species has succeeded to reclaim the degraded saline-sodic soil and to restore the soil nutrients to be more preferable for growing many plant species.

Habitat improvement was clearly shown in the comparative vegetation data between 2006 and 2011. Most of the sampling plots showed an improvement in plant density as well as diversity. But in few communities, there was a decline in plant diversity and species richness due to difference in sampling location and different number of plots constructed. Moreover, as the timing (or season) of sampling was also different, majority of the plant species recorded in 2006 were annually-growing plants with few tree species. However, the 2011 data showed more tree species and less annuals (herbs). An overall development in different plant communities with improving soil quality can be seen in this study, but drawing a conclusion was not possible due to time constraint, small number of sampling plots and replicates, and therefore further detailed studies would be highly required.

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