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INFLUENCE OF INVASIVE PLANT SPECIES ON SOIL PROPERTIES IN TROPICAL RIPARIAN ZONES

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ABSTRACT

Riparian zones are highly productive biodiversity-rich transition areas. However, the invasion of exotic plant species depletes diversity and productivity, a severe global environmental concern as they alter ecosystem services. The analysis of spatio-temporal variations of soil nutrients in an invasive plant-impacted riparian zone is significant. This study was conducted in the riparian zones of a tropical river basin, Vamanapuram river basin (VRB), Southern Western Ghats, India, to analyse soil samples (total n= 60) from invaded (VR) and uninvaded (Control) areas for pH, Electrical Conductivity (EC), Organic Carbon (OC), available nitrogen (AN), available phosphorus (AP), and available potassium (AK). In general, comparing the invaded and control sites, changes were noticed in almost all the above physico-chemical parameters (except OC) at a significant level with high values in invaded soil sites mainly due to invasion. However, more studies are needed to differentiate the impacts within the system for a better understanding of invasive plant-soil interactions.

KEY WORDS : Soil Propertie, Riparian Zones

INTRODUCTION

Plant invasion is a significant component of ongoing global change and can alter the structure and functions of ecosystems (Ehrenfeld, 2010; Ricciardi *et al*., 2017). Many studies have examined the impact of invasive plants on the diversity and abundance of soil communities in terms of direction and magnitude (Vila' *et al.,* 2011). Additionally, invasive species are known to interrupt ecosystem productivity, nutrient cycling patterns (C, N, and other elements), native plant species diversity soil organic matter, soil aggregation, the release of allelopathic substances, etc. (Vila' *et al*., 2011; Ricciardi *et al.,* 2017). In riparian ecosystems, invasive plants differ from natives concerning nutrient use strategy, quality, and quantity of litter production. For instance, invasive plants often produce more litter that decomposes faster than native plants, subsequently changing the soil's pH, moisture, and nutrient composition (Yan *et al.,* 2020). This change in soil nutrient availability allows competitively advantageous invasive species to outperform native plant communities (Zhang *et al.,* 2019; Fang *et al.,* 2021). A lack of extensive assessment of soil conditions in an ecosystem limits the interpretation level of invasion impact studies. Given this fact, the present study attempts to assess soil nutrient status and spatio-temporal changes associated with invasion stress in a tropical riparian ecosystem.

Study area

The Vamanapuram river, a small tropical mountainous river (L= 86 km), originates from Chemmunji Mottai (1717 m above MSL) in the southern Western Ghats, India (Fig.1). Vamanapuram river drains into the Arabian Sea after flowing through varied geologic and physiographic terrains. Vamanapuram river basin (VRB) experiences a tropical monsoon climate with a mean annual rainfall of ~2035 mm and a mean monthly temperature varying from 30 to 36.5 °C.

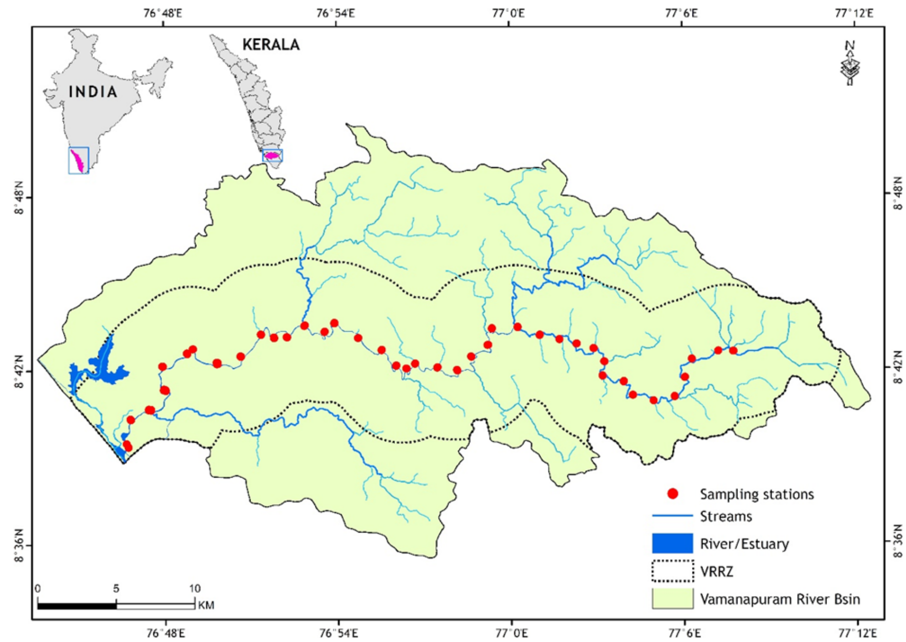

Fig. 1. Location map of Vamanapuram River basin and the sampling stations

METHODOLOGY

Sampling Scheme

A systematic stratified quadrat was set as per the National Vegetation Classification -NVC (Archaux and Bergès, 2008) in the riparian zone of VRB during 2017-2019. A total of 60 quadrats were sampled parallel to the river, covering the left and right banks ofthe river (Fig.1). Out of this, 40 sampling points were with a high infestation of invasion (VR) and 20 points without the threat of invasion (control sites). Invaded and uninvaded plots were in the same topographic situation and had the same soil texture with widely divergent plant cover. Soil samples were collected for three consecutive years (2017-2019). Physical parameters of soil such as pH, EC, OC, AN, AP, and AK were determined as per standard methods (Trivedy and Goel, 1987; Saxena, 1999; Gupta, 2007).

Statistical Analysis

All data were checked for compliance with normality assumptions, and non-normal data were subjected to various transformations based on frequency distribution. For normally distributed data, a comparison of soil parameters between VR and controlsites was made using one-way ANOVA, followed by post-hoc Tukey's HSD test. In contrast, non-parametric alternatives between groups' comparison tests, viz., Kruskal-Wallis H and post-hoc Mann-Whitney U test were applied to the data that was not normally distributed. All the statistical analyses were carried out using SPSS (V.25.0) and R (V.4.2).

RESULTS AND DISCUSSION

The results of physico-chemical parameters analyzed for the soil samples, both invaded (VR) and control sites, are presented in Table 1.

In general, soils of both invaded (VR) and control sites were acidic in nature, but more acidic in invaded soils than in control sites. For example, the pH of soils in invaded sites ranged from 3.2 to 5.8 with an average of 4.2, but the average value of control sites was 4.7. Further, except OC, other soil parameters like EC, AN, AP, and AK showed significant variations between invaded and control sites with high content in invaded sites (Table 1).

The average value of EC in invaded and Control sites was 102.7 and 82 µS/cm, respectively. In the case of soil nutrients, the invaded soils registered higher content of AN (ave.= 374.8 kg/ha), AP (= 41.1), and AK (= 176.6), in comparison with therange of AN (190.3 kg/ha), AP (6) and AK (143) of control sites. Yet, OC showed almost the same content (ave.= ~0.6 %) in both locations.

Based on the grading studies of criteria put forth by Muhr *et al.* (1965) and Sidharam *et al.* (2017), in the invaded and control samples, the OC content

Table 1. Descriptive statistics of physico-chemical parameters of soil samples

Parameters	Invaded (VR) Site			Control Site		
	Range	Mean	SD	Range	Mean	SD
pH	3.20-5.86	4.21	0.605	3.8-5.9	4.7	0.58
EC (μS/cm)	25-236	102.7	47.05	43-117	82	19.15
OC (%)	0.34-0.93	0.637	0.141	0.40-0.84	0.62	0.13
Available N (kg/ha)	100.4-863.4	374.8	165.02	108-445	190.3	91.44
Available P(kg/ha)	6.54-110	41.16	27.81	2.75-16.9	6.09	3.65
Available K(kg/ha)	72.9-349	176.6	69.1	85.5-255.4	143.04	48.8

SD-Standard deviation; EC – Electrical Conductivity; OC- Organic Carbon

was in the medium grade (grade range: 0.5-0.75%), AN and AP were in the medium grade (range: 272-544 kg/ha and 10-24 kg/ha, respectively), and AK was in the higher grade (108-280 kg/ha) in the invaded and control site samples.

In order to compare the physico-chemical parameters at invaded sites with that of control sites, statistical methods were applied. The comparative analyses showed that all soil parameters at invaded areas varied significantly (except OC) compared to the control sites. The Mann-Whitney U test and the independent t-test in year-by-year (2017-2020) analysis, too, demonstrated a similar significant change across all parameters (except OC).

Additionally, statistical analyses were carried out for soil parameters specifically for invaded sites. This exclusive statistical approach using the Kruskal Wallis test revealed a substantially significant variation in pH ($p<0.04$) and AK ($p<0.001$) values for invaded sites. Further, the Post Hoc Tests demonstrated that there had been a significant temporal shift in pH and AK. This spatial variation of soil parameters, especially pH and nutrients, between invaded and control sites warrants explanation with respect to invasive plant species.

In the study area, apart from the native riparian species, excessive growth of invasive species was also observed. These include *Sphagneticola trilobata, Mikania micrantha, Merremia vitifolia, Mimosa diplotricha var. diplotricha, Lantana camara, Chromolaena odorata, Prosopis juliflora, Parthenium hysterophorus, Senna hirsute, Acacia mearnsii, Hyptis suaveolens, Ageratina adenophora*. Many of them belonged to the IUCN world's worst weed category.

The invasive plants are usually capable of drastically changing soil characteristics such as pH, the content of C and N, nitrification rates, mineralization rates, and concentrations of essential elements such as Ca, Mg, and K (Simba *et al*., 2013). Further, Stefanowicz *et al*. (2018) reported that plant invasion drives changes in topsoil chemical composition by uplifting nutrients from deep soil horizons. Wang *et al*. (2015) demonstrated that plant invasion considerably increases soil acidity, that the nitrification process in the soil is connected to H^+ release, which further increases soil acidity, and that invasive plants' nitrogen acquisition can affect the pH of the soil.

The present study shows that the soil pH is more acidic in invaded sites than in the control sites. Other parameters like EC, AN, AP, and AK levels are high in invaded sites and are statistically significant compared to the control sites. Geologically, the study area covers lateritic soil and is generally acidic, mainly due to the presence of Fe^{3+} ions in the red-colored soil. However, the invaded soil of the study area contains more above-mentioned invasive species and littering of the leaves from both invaded and native species, followed by decomposition of leaf litter under moist, warm temperature releases carbonic acid, which further split up and releases H^+ ions into the soilimparting high acidic condition to the invaded soil. The litter decay is generally controlled by litter quality, soil moisture, soil temperature, soil nutrient availability, and soil particle size (Rai *et al*., 2021).

High-quality litters contain high nitrogen concentration, and vice versa (Rai *et al.*, 2021). The amount of available nitrogen (AN) in the invaded sites is medium grade. The nitrogen cycle plays a vital role in successful plant invasions; high nitrogen levels lead to an increase in the biomass of invasive plants and a decrease in the biomass of native plants. The litter decay also releases a notable amount of nutrients, especially N, into the topsoil and increases the soil nutrient content. Further, as Stefanowicz *et al.* (2018) suggested, the uptake of nutrients by invaded species from bottom soil may also increase the nutrient level of topsoil. Invasive plants create a microenvironment with increased nitrogen availability that would facilitate further invasion (Wang *et al.*, 2015). Many invasive species' litter decomposition increased soil nutrients, reducing the diversity of native plants and encouraging new plant invasions. The implications of litter decomposition from the invasive plant *Sphagneticola trilobata* on growth and physiology vary markedly from native species in various soils and depths (Sun *et al.*, 2022). Higher litter decomposition rates of invasive plants are usually related to higher litter quality, and invasive plants generate more available C and other resources for soil biota than native plants (Lone *et al.*, 2019).

Even though the site and species-specific study of nutrient interaction with invasive species are limited, a few studies support the above argument of nutrient enhancement in topsoil by invaded species. For example, the leaves of invasive plant *M. micrantha* identified in the study area have higher CO_2 fixation capacities than those of co-occurring native species (Deng *et al.*, 2004). Leaf N is also higher in *M. micrantha* than in the native species, and because of its higher net photosynthetic rates, the stems of *M. micrantha* have high net photosynthetic rates (Xu *et al.*, 2022). Further studies have demonstrated that invasive plants increase nitrogen transformation rates and soil nitrogen availability (Zhang *et al.*, 2019). Invasive species alter the soil physico-chemical parameters and create a microenvironment that favors their growth and establishment and suppresses the growth of native species. The invaded sites of the study area showed higher AN, indicating the role of invasive species. The impact of invasion on soil communities and nutrient cycling processes are considered an essential mechanism of the invasion success of invasive species such as *Lantana camara,* which have shown higher available nitrogen and tremendous net nitrogen potential in soil (Ehrenfeld, 2010). Further, *C. odorata* can germinate over a wide pH range and is adapted to various soil conditions (Mandal and Joshi, 2014).

The impacts of plant invasion on nitrogen and carbon cycles are often well-studied, but the effects on the phosphorous cycle and cations are seldom documented (Ehrenfeld, 2010). Higher soil phosphorus often is correlated with invasion, yet it is not usually clear whether invaders prefer microsites with high soil phosphorus or if they cause increases in available soil phosphorus (Lone *et al.*, 2019; Rai and Kim, 2020). When plant invasion causes an increase in the acidic condition of the soil, the solubility of phosphorous in the soil is enhanced, and high phosphorous availability often facilitates further invasion (Wang *et al.*, 2015). The study noted a significantly high AP in invaded sites due to the acidic condition of the soil.

Again, other studies have shown that another invasive species present in the study area, *Acacia mearnsii*, can enhance nutrient availability (N and P) in riparian surface soils (Simaika *et al*., 2018). Effects on coexistence must be considered within the context of plant–plant competition for limiting resources such as light and soil nutrients (Crawford and Knight, 2017).

SUMMARY AND CONCLUSION

This study exemplifies the influence of invasive plant species on soil properties in tropical riparian zones. For this, Spatio-temporal analyses of selected soil parameters (pH, EC, OC, AN, AP and AK) were carried out in 60 quadrats (40 invaded and 20 control sites) along the riparian zone of Vamanapuram River Basin, SW India, during 2017-2019.

The soils of both invaded (VR) and control sites were acidic in nature, but more acidic in invaded soils than in control sites. Further, except OC, other soil parameters showed statistically significant variations between invaded and control sites with high content in invaded sites. Geologically, the study area covers lateritic soil and is generally acidic. However, the invaded soil contains invasive plant species and littering of the leaves from both invaded and native species, followed by decomposition of leaf litter under moist, warm temperatures impart high acidic conditions to the invaded soil.

The litter decay also releases a notable amount of nutrients, especially N, into the topsoil and increases the soil nutrient content. Further, the uptake of nutrients by invaded species from bottom soil may also increase the nutrient level of topsoil.Among theinvasive plants in the study area, the species like *S. trilobata, M. micrantha, M. vitifolia, M. diplotricha, L. camara,* and *C. odorata,* are typical examples for further detailed study to understand the impact of invasive plants on soil chemistry. Most of the interactive components of soil and invasive plant interaction remain unexplored, and more species-specific analyses under different microclimate conditions are needed to fill this knowledge gap.

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