Forest Structure and Anthropogenic Disturbances Regulate Plant Invasion in Urban Forests

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Abstract

Urban forest ecosystems, the structure and functions therein, are subjected to anthropogenic disturbances. Native and sensitive species from those forests might be lost due to such disturbances. At the same time, supplemented anthropogenic resources might create opportunities for exotic and invasive species. Although, invasive species are considered as one of the major threats to the urban biodiversity and ecosystems, the researches on invasion dynamics in the Himalayas have mostly focused on the impacts of invasion on forest structure and productivity. This study aims to understand the influence of forest structure and anthropogenic factors in invasion success that are poorly covered in the existing literature. We selected 11 urban forest patches for the study considering the presence-absence of selected invasive species and structural attributes. We used Principal Component Analysis (PCA) to reduce co-linearity in the covariates and generalized linear mixed effects model (GLMM) to identify the factors affecting the invasion success. We found that the structural attributes of the forests and anthropogenic disturbances regulated invasion success in urban forests. This implies that maintaining urban forest structural attributes, especially maintaining the stands with large-sized trees, are essential to regulate and control invasion in the context of urbanization.

Introduction

Urban green spaces represented by diverse habitat types ranging from the highly managed green infrastructures like green roofs to the remnant patches of urban forest are crucial for habitat connectivity and ecosystem service perspectives (Milanovich et al. 2012; Aronson et al. 2017). They play a vital role to make towns and cities habitable area through the abatement of pollutants such as ozone, acting against the impacts of urban heat islands, moderating local climate, and enhancing thermal comfort (Klemm et al. 2015; Ballinas and Barradas 2016; Calfapietra et al. 2016; Jaganmohan et al. 2016; Livesley et al. 2016). Globally, as the rate of urbanization and biodiversity loss are analogous to each other, understanding the ecology of urban forests individually and within the network is essential for biodiversity conservation perspectives (Brook et al. 2008; Aronson et al. 2017). Due to the high density of people and the greater prevalence of the human-mediated mobility of the commodities, human-ecosystem interactions differ significantly in the city areas compared to other natural sites. This difference in interaction results in different patterns and processes of invasion in the urban context compared to natural sites (Gaertner et al. 2017).

Habitat patches within the cities are highly fragmented and heterogeneous, and abiotic and biotic environments are greatly altered, which affect local (alpha) or within-patch biodiversity (Faeth et al. 2012). Urban areas are often considered inhospitable for native species, especially sensitive ones, but the case is different for invasive species (Cadotte et al. 2017). As invasive species are opportunistic, the niches created due to the disappearance of the native species are occupied by invasive ones. As the urbanization proceeds, the non-native invasive species gradually replace the native species from the ecosystem of city areas (Cadotte et al. 2017). Urban areas are important in invasion research as they act both as entry points and dispersal locations for the invasive species (Gaertner et al. 2017; McLean et al.

2017). As the result, the diversity and abundance of the non-native invasive species are greater in city areas compared to their rural counterparts and other natural sites (Cadotte et al. 2017). Urban green space including the urban forests are the hotspots of biological invasion (Gaertner et al. 2017). As the urban green spaces are subject to high human pressure, they often consist of high human trails and other interactions which enhance edge and serve as propelling factor for opportunistic invasive species (McDonald and Urban 2006). However, the level of invasion and ecological success of invasive species are often regulated by context-specific factors (Dyderski and Jagodziński 2019).

Urban ecosystems may be one of the final frontiers of ecological exploration (Dolan et al. 2013). Mainstays of urban biodiversity are the urban forest patches, embedded in the matrix of urban infrastructure, remnants, or naturalized plantations. Though, urban ecological research is swirling in recent times (Lepczyk et al. 2017), limited information exists about the dynamics of urban forests in developing countries. Increased anthropogenic activities and increasing demands of ecosystem services have intensified both the stress and appeals of such areas. However, the invasion of such important areas as one of the most important threats has not been dealt with in detail. Invasive plant species bring a profound impact on the trophic structure of forest ecosystem (McCary et al. 2016). As developing countries have limited capacity to apply remedy measures against the problem of ecological invasion (Early et al. 2016), it is crucial to understand the factors that offer resistance of the ecosystem against invasion.

Rapidly urbanizing landscapes in developing nations with several urban forest patches provide an opportunity to deal with the ecological role of forest structure relating to the invasion and future vulnerability. In the face of growing challenges, understanding the factors which regulate the temporal and spatial dynamics is crucial for conserving urban biodiversity. Despite invasion being the subject of interest for more than six decades following the pioneering work of Elton (1958), we are yet to reach a common understanding of the factors responsible to drive the invasion of the species. In the case of urban areas, the problem is even severe as invasion science has yet to give significant attention to the invasion dynamics, patterns, and processes in the urban ecosystem (Gaertner et al. 2017).

There is a considerable debate on the factors associated with the invasion of the urban sites with invasive species. Native species richness can buffer the impact of invasive species when the sites are undisturbed but not the same when the sites are disturbed (Pinto and Ortega 2016). Understanding the role of forest dynamics and structural control on the spread of invasive species is essential to formulate the management plan (Baret et al. 2008). In the context of knowledge void regarding the implication of tree species richness, abundance, and forest structure on the regulation of invasion of the urban forest, this study aimed at generating information on two fronts: i) to assess the role site-level disturbances play on the invasion probability within the urban forests and ii) comprehend the importance of structural attributes of forests to provide defense against invasion. For this purpose, factors associated with the occurrence of invasive species in urban forests were explored employing a correlational approach followed by predictive modeling. Our study focuses on Kathmandu valley, Nepal is envisaged to fill the knowledge gap on the factors regulating the presence of invasive species in urban forest patches.

Materials And Methods

Study area

Kathmandu, a bowl-shaped valley, encompassing an area of around 899 km^2 of three districts, Kathmandu, Lalitpur, and Bhaktapur, lies at 1,300 meters above sea level (m asl) and is located between latitudes 27°32’13” and 27°49’10” N and longitudes 85°11’31” and 85°31’38” E (Khanal et al. 2019). The valley is surrounded by the Mahabharat mountain range, with four hills namely Chandragiri, Nagarjun, Phulchowki, and Shivapuri, on all sides with the highest altitude being 2,831 m asl (Phulchowki). The climate is subtropical, temperate, and cool-temperate, with four distinct seasons: spring (March-May); summer (June -August); autumn (September -November); and winter (December -February) (Pandey et al. 2010). The mountains are forested in upper reaches, most of these in the regenerating stage and mature hardwood forests confined to parks and sacred areas.

Nepal is one of the fastest urbanizing nations in the world with the urban population growth exceeding 6% since 1970s and Kathmandu has been the center of urbanization where the built-up area almost doubled resulting in the expansion of settlements outwards in all directions in the period between 2000 and 2018 (Khanal et al. 2019). In the valley slope, agricultural land has been converted to forest land while, on the valley floor, nearly 1000 ha of forest have been converted to agricultural land and built-up area (Ishtiaque et al. 2017). Agriculture in the valley is characterized by very intensive farming use of fertilizers, irrigation, human labor, and terracing of farmland. The Bagmati is the principal river originating from Shivapuri ridge at an elevation of about 2,650 m asl and drops to 1,340 m asl over a distance of about 8 km with a network of 20 tributaries (ICIMOD/MoEST/UNEP 2007). There are several forest patches embedded in the urban matrix of Kathmandu valley creating a mosaic of green areas. For this research, we studied 11 patches of forests within three districts of Kathmandu valley (Fig. 1).

Vegetation surveys

Vegetation surveys were conducted in each sample forest patch in October and November 2015. These surveys included trees using quadrates of size 250 m^2 (circular). All sampled trees were measured for diameter at breast height (DBH) (Diameter tape) and height (Clinometer- Suunto PM-5/360 PC Clinometer) and were identified up to species level in the field. For unidentified species, specimens like leaves and flowers were collected and identified in Tribhuvan University Herbarium (TUH), Kathmandu. If the identity was not clear, the tree species were placed in the unidentified category (abbreviated as UN1, UN2, etc.). We considered three main invasive species for the study namely *Ageratina adenophora, Lantana camera, and Parthenium hysterophorus*, as they are considered obnoxious weeds in the valley (Taylor et al. 2012; Maharjan et al. 2015; Shrestha et al. 2015; Thapa et al. 2017). We recorded the presence of invasive species in a plot if it had at least a species established in a plot. Although we did not measure the height or biomass of the individuals or clumps, we ensured the established species using expert judgments in the field. Other variables such as trail distance, canopy cover, leaf litter conditions, ground vegetation, tree richness, and tree number in sample plots were surveyed in the field (Table 1).

Table 1
Description of variables used for analysis

SN	Variables	Description
1	Mean diameter of tree within sampling plot (TRmean.DBH)	Average diameter of all trees within 250 m^2 plot measured at 1.3 m above the ground measured with diameter tape
2	Average tree height within sampling plot (Trmean.ht)	The average height of all the tree within the sampling plot measured with clinometer
3	Tree Abundance (Trabundance)	Number of individuals of tree per hector within the sampling plot
4	Tree richness within the sampling plot (TRichness)	Number of species of trees within the sampling plot
5	Maximum diameter within the sampling plot (DBHmax)	The diameter of the tree (cm) with maximum girth size at 1.3 m above the ground surface
6	Maximum height of tree within the sampling plot (Heightmax)	The height of the tallest tree (m) within the sampling plot
7	Canopy cove (Tcanopy)	Canopy cover of the aboveground or trees measured as % of cover in the plot
8	Litter Condition	The cover of ground surface by the leaf litter, **Abundant** (Abu) for all the plot (> 70%) covered by litter, **Sparse** for 30–70 % of plot covered and **Rare** for < 30% covered with litter
9	Distance from Trail	Distance (m) of the sampling plot from the nearest human trail
10	Ground Cover	Percentage cover of the vegetation on the ground

Data management and analysis

We used data exploration techniques such as descriptive statistics and visualization for the general idea about the data and variables. Since our predictor variables (related to tree structure) were highly correlated, we used principal component analysis (PCA) using package FactoMineR (Lê et al. 2008) to obtain orthogonal principal components. We selected the first five components that explained > 90% cumulative variance for further analysis. We checked the major contribution of individual covariates to these components. We used the selected PCs, litter conditions, and trail distance as predictor variables for regression model building. We used the generalized linear mixed effects model (GLMM) using package lme4 (Bates et al. 2015) to model the probability of the presence of invasive alien plants (IAPs). Since we modeled the presence/absence of the IAPs in the plots, we build the regression model using binomial error structure of the response.

As the design involved plots nested in forests, we modeled two level grouping factors. However, the variance due to plots was too low thus we removed the ‘plot’ as a grouping variable and hence used only ‘forest’ as random intercept in the model. We started with the most complex model following (Zuur et al. 2009) where we used two grouping variables (plots nested in forests) and checked the model outputs to decide what variable to retain in the model. The model selection, for the fixed effects variables, used the information criteria approach (Burnham and Anderson 2004) using the backward elimination method, removing an insignificant variable one at a time until all the variables and design variables were significant, checking AIC values and chi-square test significance. We used Bobyqa optimizer with 10^7 iterations while modeling. We did not scale the covariates in continuous scale as the model did not show any convergence issues without scaling. We built models with Laplace Approximation, Gauss Hermite Quadratures with 10 and 25 Quadratures. Although the models did not vary among three methods (Fig. SI-A), we preferred adaptive Gauss-Hermite quadrature approach with AGQ = 25, since the samples between clusters (groups) were unequal and some groups had smaller sample sizes.

The trail distance had marginal effects on invasion probability. We checked the model by removing ‘Trail’ and AIC value increased (though non-significant, AIC of the model without trail was 148.56, and while included AIC was 147.74 with 1 degree of freedom lost). Moreover, the residual behavior showed significant problems in excluding the trail and therefore it was retained in the final model. Overall model diagnostics was carried out using simulated residuals following library DHARMA (Hartig 2020) which also provides a test for overall uniformity using One-sample Kolmogorov-Smirnov test. Model diagnostics also involved visual plots of Pearson Residuals for linearity using each numeric covariate and sensitivity using Pearson residuals and leverage (Fig. SI-C1 and C2). The final model showed no significant issues. We used 2000 simulations of model coefficients to obtain credible intervals using posterior distribution in the package arm (Gelman and Su 2020) to overcome the issues of confidence intervals in GLMM. Pseudo R^2 values were calculated using package MuMIn (Barton 2020) following (Nakagawa et al. 2017). We calculated the intraclass correlation coefficient (ICC) for the final model to see the portion of variance captured by grouping variables. All the analyses were carried out using R (R Core Team 2020), and visualization used ggplot2 (Wickham 2016).

Results

Descriptive Statistics

All the measured variables within studied forest patches showed variations in parameter values (Table 2).

Table 2
Descriptive statistics for numeric covariates studied

SN	Variables	Mean ± SD (Range)
1.	Average tree diameter in sampling plot (TRmean.dbh)	30.87 ± 11.36 (15-71.3)
2.	Average tree height within sampling plot (Trmean.ht)	12.33 ± 2.91 (6.86–22.87)
3.	Tree abundance (Trabundance)	12.46 ± 5.21 (3–26)
4.	Tree richness within the sampling plot (TRichness)	3.56 ± 1.66 (1–9)
5.	Maximum diameter within the sampling plot (DBHmax)	67.61 ± 33.51 (21–220)
6.	Maximum height of tree within the sampling plot (Heightmax)	18.82 ± 5.22 (18–35)
7.	Canopy cover (Tcanopy)	69.96 ± 15.26(2–95)
8.	Distance from trail (m)	9.03 ± 14.55 (0-100)
9.	Ground cover (%)	62.36 ± 22.72 (5-100)

The Eigenvalues for the first three principal components were more than 1 with the only first component Eigenvalue more than two. It took five principal components to capture more than 90% of the cumulative variance in data (Table 3).

Table 3
Eigenvalues and variance associated with individual principal components. About 93% of the cumulative variance was explained by the first five principal components

Principal Component	PC1	PC2	PC3	PC4	PC5
Eigenvalue	2.616	1.353	1.062	0.768	0.691
Variance (%)	37.381	19.334	15.182	10.974	9.868
Cumulative variance (%)	37.381	56.715	71.897	82.872	92.741

Among the variables used in PCA, plot-level average DBH and Height, and largest tree DBH and Height *viz.* tree size showed a high correlation to the first principal component. Plot level tree number and richness had the highest correlation with the second principal component. The third principal component was found positively correlated to canopy cover and the fourth component showed high correlation to number of trees in the plot. The results show main contribution of tree size, richness and number, and canopy cover in the first, second, and third principal components respectively as shown in the correlation circle (Fig. 2). We selected the first five components (Table 4) that explained around 93% of the variance.

Table 4
Correlation of the variables with the first five principal components. The correlation values > 0.6 are in bold

Variables	PC1	PC2	PC3	PC4	PC5
TRmean.dbh	**0.79**	-0.13	-0.31	-0.03	0.41
Trmean.ht	**0.75**	-0.34	0.33	0.19	-0.19
Trabundance	-0.35	**0.61**	0.24	**0.61**	0.19
TRichness	0.24	**0.71**	-0.37	-0.19	-0.47
DBHmax	**0.74**	0.44	-0.21	0.019	0.32
Heightmax	**0.81**	-0.005	0.23	0.28	-0.32
Canopy.cover	0.19	0.37	**0.75**	-0.48	0.15

This is clear that the probability of invasion decreases with an increase in PC1 values and PC3 values. The anthropogenic disturbance, in terms of forest trails, has a negative relationship with invasion whereas; higher leaf litter condition is seen to lower the invasion probability (Fig. 3).

The model dispersion test showed no significant over dispersion (ratio = 0.93, χ^2 = 128.63, rdf = 139, p = 0.72). The R^2 value (marginal = 0.34 and conditional = 0.44) showed that about 10% more variance was contributed by forests as grouping variable which is further confirmed by intra-class correlation (ICC = 0.35).

Table 5
Summary of fixed effects retained in minimum adequate model using GLMM where the probability of invasive species present in urban forest patches is modeled as the response variable. As the model convergence did not show any issues, we used un-scaled continuous variables. The credible intervals (2.5% & 97.5%) were obtained by simulations of posterior distributions of model coefficients

Coefficient	Estimate	Std. Error	z value	Pr(>|z|)	CRI 2.5%	CRI 97.5%
Intercept	0.286	0.497	0.575	0.565	-0.669	1.205
PC1	-0.318	0.145	-2.198	**0.027**	-0.599	-0.042
PC3	-0.719	0.273	-2.625	**0.008**	-1.23	-0.193
Litter.conditionRar	2.021	0.832	2.429	**0.015**	0.417	3.625
Litter.conditionSpr	1.877	0.581	3.23	**0.001**	0.792	2.997
Trail	-0.03	0.018	-1.62	0.105	-0.067	0.006

Probability of invasive species presence was found significantly negatively related with PC1 (β = -0.318, z = -2.19, p = 0.027) and PC3 (β = -0.719, z = -2.62, p = 0.008). The unit increase in PC1 value is found to reduce the probability of invasive species presence by about 7% and the unit increase in PC3 reduces the probability of invasive species presence by about 17% considering other covariates constant. The mean invasive species presence probability for abundant leaf litter condition was found 0.57 and that increased to 0.89 and 0.91 for sparse and rare litter conditions respectively (Table 5). The distance of forest trails to sampling plots was found to have a negative relationship (Fig. SI- B) with the presence of IAPS but was not significant (β = -0.03, z = -1.62, p = 0.105).

It is seen that IAPs invasion decreases under abundant (Abu) and sparse (Spr) leaf litter conditions whereas increase under rare (Rar) leaf litter conditions (Fig. 4). Probability of invasive species presence is found to decrease with values of PC3 for all the categories of leaf litter condition namely, abundant (Abu), sparse (Spr), and rare (Rar) (Fig. 5).

Discussion

Communities around the world, traditionally protect natural sites that are dedicated to ancestral spirits or deities, and these sacred grooves and other urban forests are crucial for habitat protection and biodiversity conservation in the face of the constant anthropogenic pressure subjected towards a natural ecosystem in urban areas (Bhagwat and Rutte 2006; Tordoni et al. 2017). Similarly, most of the urban green space in Kathmandu valley, prominently the larger patches, are represented by urban sacred grooves (Mansberger 1991). However, in Nepal's urban areas like Kathmandu, we have not managed the information to show the biodiversity status of urban areas and how the urban biodiversity should be maintained. In this study focusing on Kathmandu valley, we found that structural components of the forest exert resistance against the invasion by selected exotic plants. Additionally, the response of invasive species also varies significantly among the forest patches. This finding implies that the structural complexity of the forest should be integrated into the management decision of urban forests.

Forest structure and invasion

The dominance of the tree was found to be the major factor to resist the invasion. In our case, the probability of the occurrence of invasive species decreased along the first principal axis represented by both stand level and individual tree size (DBH and height). The horizontal and vertical measures of the trees especially those of the large-sized trees are important contributors to the structural complexity of the forest ecosystem (Seidel et al. 2019). The inverse relation of the probability of invasion with the first principal axis can be interpreted as the structural control of trees on the invasion. This entails maintaining dominance is crucial to resist the invasion. Different functional aspects of the forest ecosystem such as carbon sequestration, ecosystem regulation, biomass production, etc. are largely regulated by large-sized trees and are considered important components of the forest ecosystem (Lutz et al. 2018; Ali et al. 2019). They can also regulate the micro-and meso-climatic variables of the environment (Lindenmayer and Laurance 2017). Availability of the resources such as light, moisture, and soil fertility are crucial for the successful establishment of invasive species (Dyderski and Jagodziński 2019). The filter of the invasive species in the area with the high diameter and high basal area can be related to the regulation of the resources available to the invasive species in the forests.

The negative relation of occurrence of the invasive species to the third principal axis, contributed by canopy coverage, implies that canopy cover regulates the amount and intensity of the light received by the understory invasive species. The amount and intensity of the light in turn regulate the nutrient uptake and germination success of invasive species (Dyderski and Jagodziński 2019). This ultimately results in a low occurrence of invasive species in high canopy areas.

Disturbance and invasion

High population density proximity to urban forests poses strong recreational pressures that contribute to the loss of biodiversity (Vakhlamova et al. 2016). When the forests are exposed to a high level of disturbances, native species are removed creating space for invasion by the alien species (Bonanomi et al. 2018). Areas with high human interference usually contain high variety of invasive and alien species (Mavimbela et al. 2018). Canopy cover represents the structural attribute of the forest and canopy opening is considered an indicator of the disturbance. With increased disturbance, gaps are created on the canopy. Furthermore, though marginally significant in our case, the occurrence of the invasive species is negatively associated with the distance from the trail. Trails and the gaps in the canopy will create an open niche for species (Baret et al. 2008). Trails have been reported to be the facilitator of invasive species dispersal in urban forest ecosystems (Kang et al. 2019). Furthermore, trails influence understory vegetation (Lapaix et al. 2012), resulting in soil compaction and litter removal from the surface thus exposing the soil for opportunistic species.

Leaf litter cover was found to be another significant predictor of the invasive species occurrence in the urban forests. The probability of the occurrence of the invasive species found significantly higher in the areas with rare or sparse leaf litter conditions compared to the abundant leaf litter conditions can be related to the disturbance-invasion relationship. In the area with the abundance of leaf litter, the amount of light that gets transmitted is low compared to the areas with rare to sparse leaf litter conditions, impacting the germination success of the invasive species seeds (Setterfield et al. 2005). Researches have shown that the alien species richness, not considered in our study, is found to increase significantly with disturbance in the forest habitat (Alston and Richardson 2006). Furthermore, the probability of the occurrence of the invasive species increased even along with the first principal component when the leaf litter condition was rare while the opposite relation was observed for sparse and abundant litter coverage. However, the probability of the occurrence of invasive species decreased along with the third principal component in all conditions of leaf litter coverage. This indicates that structural controls of the invasion are regulated by the leaf litter cover while the canopy itself can contend the invasion.

According to the theory proposed by Elton (1958), increased species richness should confer a higher degree of invasion resistance. In our case, neither species richness nor tree abundance was retained in the final model indicating the influence of the structural complexity and disturbance to be more important than the species richness. It is inferred from the results that leaf litter management and maintaining structural complexity is of paramount importance in urban forests to control the invasion. Furthermore, trail management can somehow help to contain invasive species distribution in urban forests. Currently, a large number of informal trails criss-cross the urban forest patches within Kathmandu valley. Approximately a population of about 2.5 million is expected to interact with forests for pilgrimage or recreation. The informal trails are then turned to formal trails with increased width and soil erosion. Unmanaged trail can initiates the widespread network of trails by trampling impacts that ultimately facilitate invasion. Unmanaged trail systems promote invasion by decreasing the canopy cover of urban forest patches. Therefore, reducing the amount of light received by the invasive species, which will reduce the germination success of the invasive species (Setterfield et al. 2005) is vital for controlling invasive species in urban forests.

Conclusion

The forests are invaded by several species of plants and certain features of urban forest patch such as tree size and stand height has a role in promoting or filtering the success of the invasive plant species. As urbanization-induced mobility creates a suitable niche for invasive species through disturbance of the forest floor, structural control can be applied through the increased stock of large trees. As larger trees with wider canopy are seen to control plant invasion in urban green spaces, conserving the remnant trees in such areas is essential. Leaf litter conditions when left high with minimal disturbance also contribute to checking the invasion. The large trees, ecologically important habitat for urban birds and other animal taxa, act as a natural control of invasive species burden. Thus, urban plantation and trail management can be leveled to reduce the burden of plant invasions in urban green spaces of subtropical regions. Rather than maintaining a dense canopy of small trees, we recommend retaining larger trees with a wider canopy to maintain the structural complexity. However, the quantification of invasive species burden in terms of biomass or density will clarify the notion of safe areas in urban forests in urban centers in the subtropical Himalayas.

Declarations

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Authors' contributions:

PCA conceptualized the study, PCA, KB, DC, SRM, MKD conducted the field. PCA & CA analyzed the data, PCA & CA wrote the draft paper, and all the authors reviewed and edited the paper.

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Figures

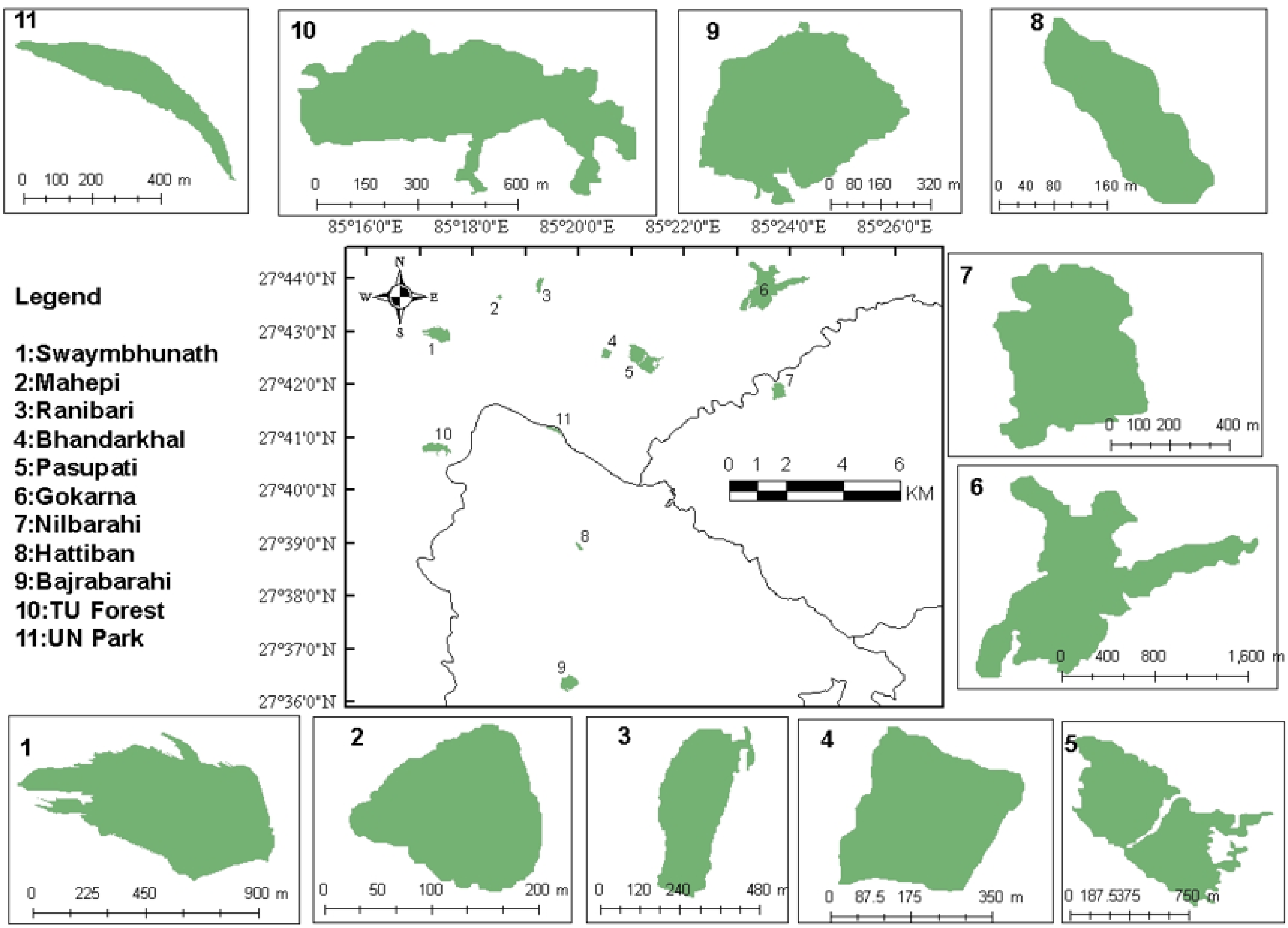

Figure 1

Study forest patches in Kathmandu valley. The scale for individual forest patch is shown and central box showsdistribution of forest patches in Kathmandu Valley, Nepal. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

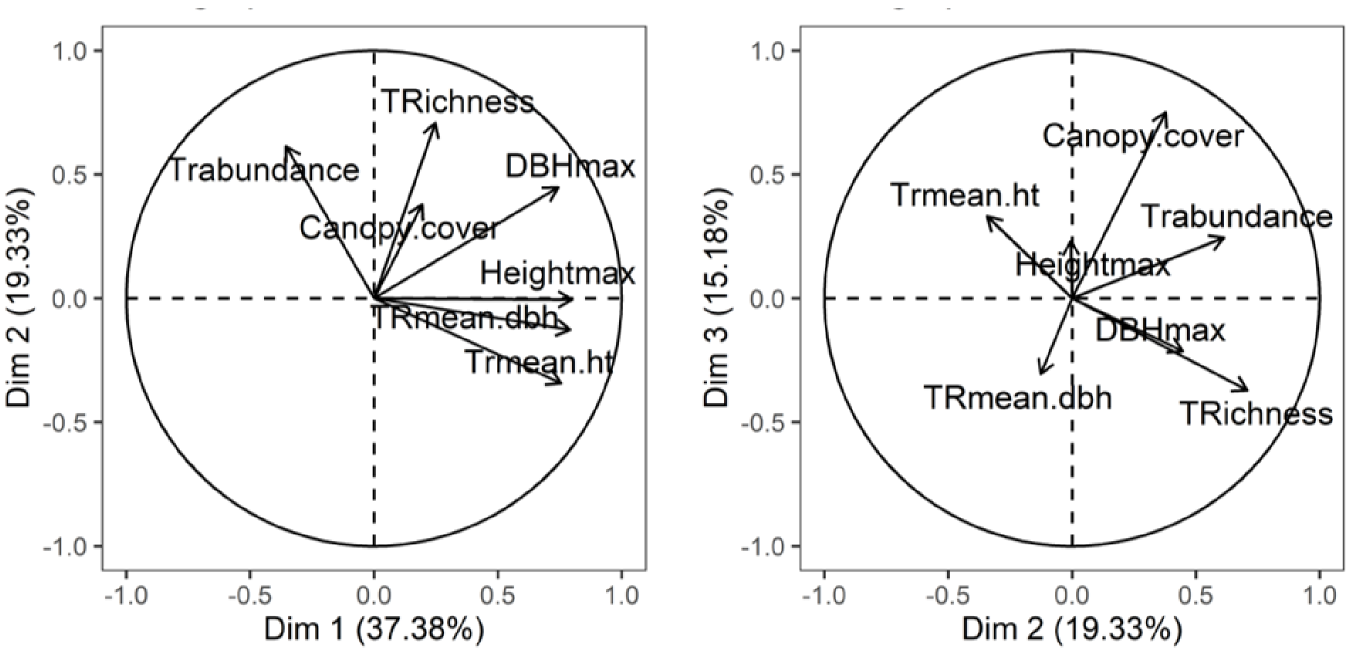

Figure 2

The correlation circles showing the correlation of variables and principal components. The first correlation circle shows variable relations to PC1 and PC2 while the second circle shows variable relations to PC2 and PC3. It is seen that PC1 is represented by tree structure parameters viz. stand-level average DBH and height, as well as largest tree DBH and height were whereas PC2 is represented by tree species richness and number. PC3 is largely represented by canopy cover

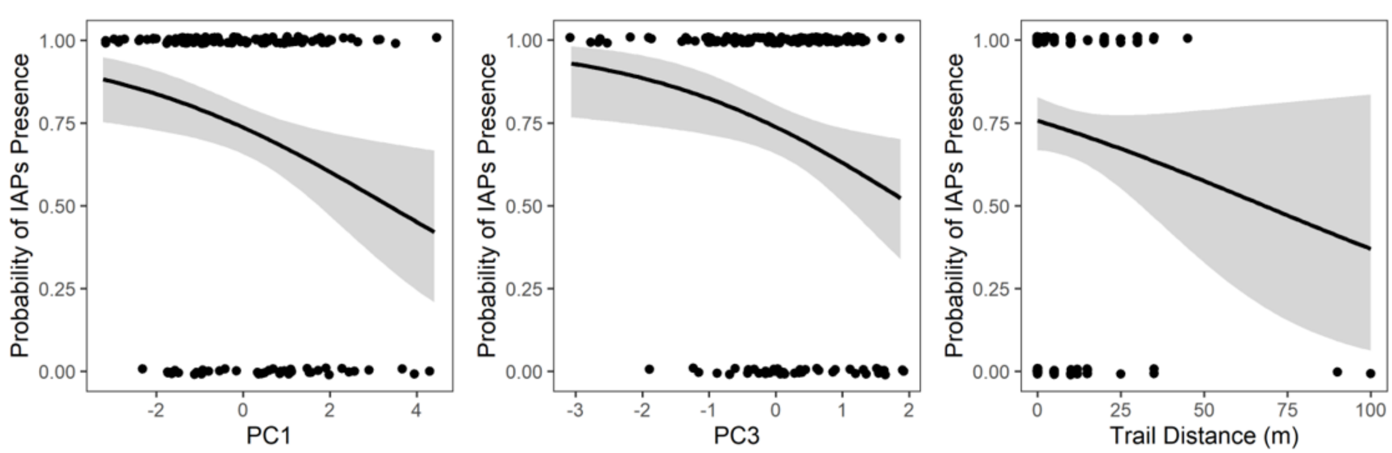

Figure 3

Representation of relationship of three covariates, PC1, PC3, and Trail distance, with probability of presence of IAPs in urban forest patches of Kathmandu valley. The grey area in the figures shows confidence interval and black curves represent predicted probability

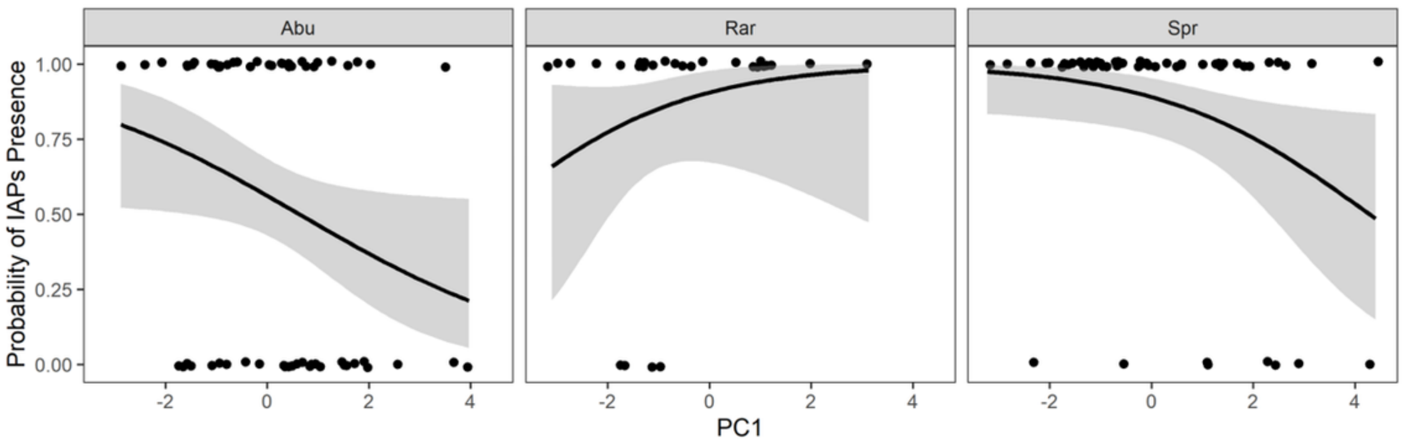

Figure 4

Probability of IAPs presence with respect to PC1 values for different leaf litter conditions in urban forest patches of Kathmandu valley. Grey region represents confidence region and black lines are predicted values

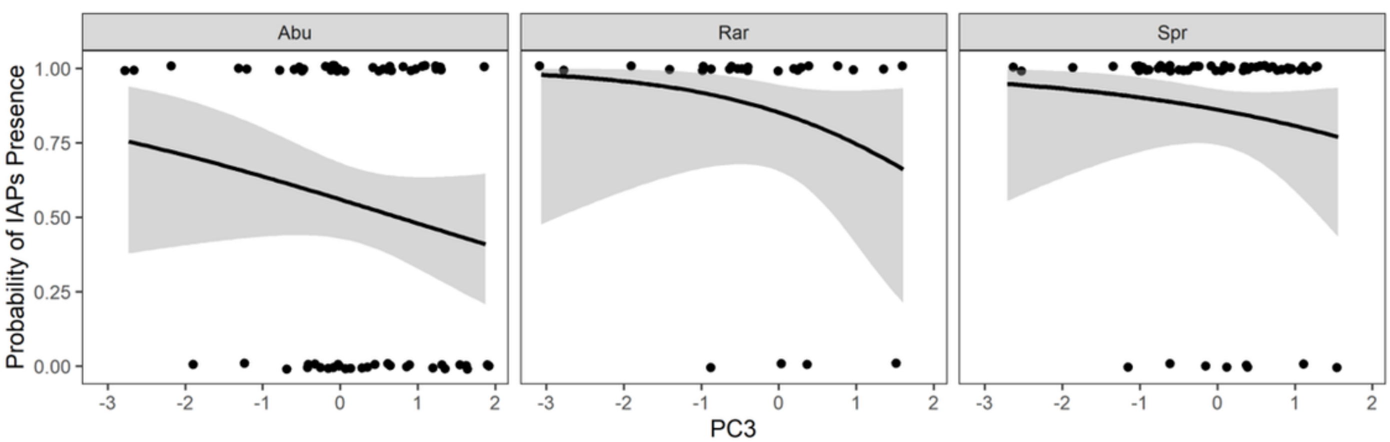

Figure 5

Probability of invasive species present in relation to PC3 for plot-level leaf litter conditions. The black points are observed values, black lines represent predicted values, and grey regions represent 95% confidence intervals

Supplementary Files

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