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BROUSSONETIA PAPYRIFERA (L.) L'HÉR. EX VENT.: AN ENVIRONMENTAL CONSTRAINT ON THE HIMALAYAN FOOTHILLS VEGETATION

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Abstract

Biological invasion caused by the non-indigenous plant species have been considered as one of the major threat to the native vegetation and its diversity at local, regional and global level and its effect on native forest ecosystem is regarded as one of the most critical issues confronting environmental conservationists. This study addresses the influence of *Broussonetia papyrifera* on the native scrub forest at the Himalayan Foothills, Islamabad, Pakistan and its relationship with ecological gradients which are important in terms of its spatial distribution. Floristic species composition and environmental factors were measured from 77 plots from two sites of the scrub forest at the lower elevation of Margalla Hills National Park Islamabad. Agglomerative hierarchical Cluster Analysis (CA) was used for species assemblage patterns and ordination analyses such as Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) was used to establish the relationship with the underlying ecological gradients. CA divided the plots into three vegetation zones: a vegetation zone comprised of species of native scrub forest dominated by *Acacia modesta*; a transition vegetation zone where *B. papyrifera* was present either in scattered form amongst the scrub forest species or showed patchy distribution and invasive vegetation zone dominated by *B. papyrifera*. Man Whitney U-test was used to find out if vegetation zones identified by CA could be significantly different from each other based on the measured environmental factors. Factor Analysis (FA)/Principal Components Analysis (PCA) were used to identify set of environmental factors/predictors, which can best discriminate vegetation zones. FA/PCA (raw varimax rotated) on the environmental factors renders three varifactors with eigenvalues higher than 1.0 accounting for over 72% of total variance. Multivariate analyses indicated that the spatial distribution of *B. papyrifera* is related to edaphic factors such as the soil texture, organic matter and moisture contents. The distribution was insensitive to the topographic factors. The probable consequences of *B. papyrifera* invasion for future scrub forest composition and plant species diversity are also discussed. The findings of this research will be used in formulating scientifically sound management and conservation strategy for the forest ecosystems of the Margalla Hills National Park Islamabad.

Introduction

Exotic introduced plants are one of the primary threats to biodiversity causing depletion, extinction, habitat loss and degradation (Anon., 1992). The disturbances caused by their colonization and establishment in an ecosystem manifest alterations in community structure and ecosystem function (Stohlgren *et al.*, 2001). Habitat disturbance either natural (fire or flooding) or human related (Fosaa, 2004) have been found closely related with non-native species spatial distribution. Similarly, the ecological effects of non-native plant species have been well documented at the population, community and ecosystem levels as have the economic costs associated with environmental damage

(Mack *et al*., 2000; Gray, 2005). There effect on the species diversity and their spatial distribution patterns are related to the variation in physiographic and edaphic conditions. Invasive plant species have the ability to bring variation in the history of anthropogenic and natural disturbances (Pauchard & Alaback, 2004). Alien plants have showed broad distribution throughout the world, in agriculture, forest and natural areas displacing native vegetation, stunting or diminishing the growth or development or establishment of native plants (Stohlgren *et al.*, 2001; Pauchard *et al.*, 2004). Invasive plant species have in common the ability to spread and reproduce rapidly; thus, overcoming biological, physical and environmental thresholds. Some of the invaders arrive by accident whereas the majorities are introduced intentionally. This prodigy has been greatly demonstrated in almost all parts of the globe ranging from tropics to arctic regions. In subtropical forests, invasion by plant alien species is a real threat to local environment and its biodiversity due to the habitat degradation (Malik & Husain, 2006a). For example, from last three decades, subtropical forest in the Himalayas foothills of Pakistan has been invaded by *Broussonetia papyrifera*, the largest possible invasion of woody species in this area ever known. Albeit many non-native plant species that has been introduced to Pakistan and has become problematic, *Broussonetia papyrifera* is listed amongst the six worst plants invaders of highly impact species in Pakistan (Khatoon & Ali, 1999). Due to its adverse effect on the native vegetation, it has been considered as one of the most unwieldy woody exotics in the Himalayas foothills (Malik & Husain, 2006a) and is widely established within the Margalla Hills National Park (MHNP) located in the foothills of Himalaya. The effect of *Broussonetia papyrifera* on native vegetation is regarded as one of the most critical issue confronting the MHNP managers today. The ecological effect of this species has not been documented hitherto. It has shown vigorous growth extending over large areas excluding many other plant species, so invaded areas have considerably lower richness and diversity of herbaceous as well as woody species. Furthermore, its growth is enhanced and associated in sites with greater water, though it is capable of occupying dry sites (Malik & Husain, 2006a). It is a large, fast growing, deciduous tree, native to Asia common in China and Japan (Parker, 1992; Huston, 2004), widespread in tropical and subtropical regions. It has become dominant in and around Islamabad, the capital city of Pakistan and is thriving along streams and nallahs where the maximum moisture is available for its growth. It was introduced in Islamabad about 40 years ago and exhibited aggressive growth and has a shallow root system that makes the trees susceptible to blow over during high winds. It is also one of the main causes of inhalant allergy in Islamabad, although it is very common in and around Islamabad, it is also reported in other parts of country (Khatoon & Ali, 1999). The rapid growth of *B. papyrifera* and effective dispersal by birds probably contribute to its success.

This study addresses what influence does the *B. papyrifera* have on the native species and what are the possible environmental factors which are important in terms of its spatial distribution? Does the plant community structure and edaphic characteristics of community structure of sites invaded by *B. papyrifera* differ from sites where it has not invaded yet? Based on these findings, the probable consequences of *B. papyrifera* invasion for future scrub forest composition and plant species diversity will be discussed. The findings will be used in formulating scientifically sound management and conservation strategies for the forest ecosystems of the MHNP (Margalla Hills National Park Specie Conservation Strategy in Prep).

Materials and Methods

The study area 33°48'N, 73°10'E.500-00 m a.s.l is located half a kilometer from the centre of the Islamabad, a capital of Pakistan (Fig. 1) with annual rainfall of 1200mm, mostly falling during March, June and July, and mean annual temperature 35°C. Mostly vegetation is invaded by the *B. papyrifera*, which have been introduced in early 1960s. The present landscape of the study area consists of mosaic of scrub forest species dominated by *Acacia modesta*, *Lantana camara*, *Justicia adhatoda*, *Dodonea viscosa* and *Pinus roxburghii*.

Field work was carried out in April, May and June 2005. Vegetation and environmental variables were measured in 77 20xm20m plots In each plot the exact location of plots (latitude and longitude) was established in the field by Global Positioning System (GPS) Garmin eTrex™ Navigator. Within each 20m x 20m plot, the percentage cover of herb, shrub and tree species was recorded. All plant species were identified and their percentage cover was estimated. Soil samples were collected from each plot from 15–35cm depth. These were air dried, grinded and passed through 2mm sieve and analyzed for pH, organic matter, nitrate contents, soil moisture and texture.

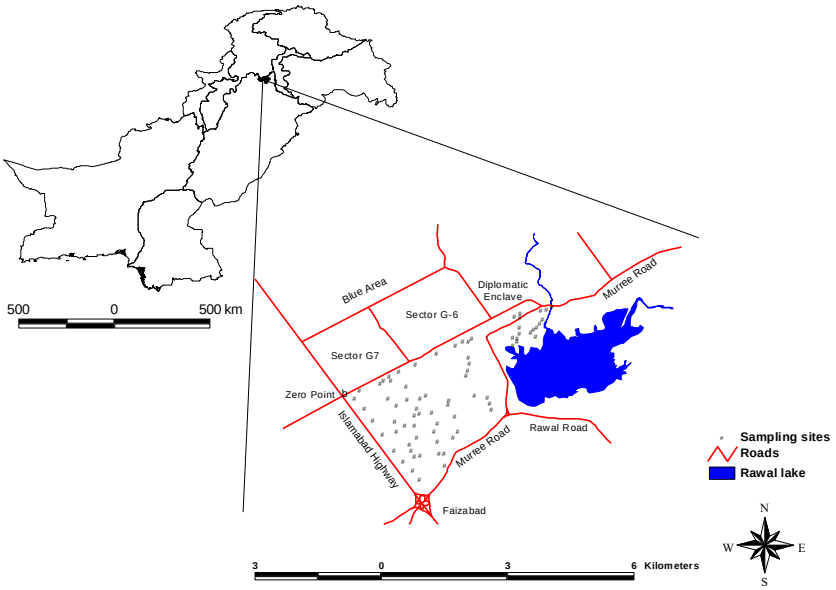

Fig. 1. Location of the study area showing the distribution of plots.

In order to search for patterns of species assemblage Cluster analysis (CA) was applied to the 77 plots by 112 species matrix of percentage cover values, using agglomerative hierarchical clustering based on floristic similarity and dissimilarity. Sorensen index was used as similarity/dissimilarity matrix between the floristic compositions of sampling plots. Factor Analysis (FA)/Principal Components Analysis (PCA) was used to identify a set of environmental predictors/factors, which can best discriminate vegetation zones identified using CA. Floristic data matrix was subjected to Detrended Correspondence Analysis (DCA) to search the possible underlying gradient

important for spatial distribution of *B. papyrifera* invasion. Environmental variables of each plot were compared with vegetation characteristics by means of the Canonical Correspondence Analysis (CCA). The significant environmental factors discriminated by FA/PCA were used in CCA along with the floristic matrix. To assess the significance in the CCA axes, Monte Carlo simulations were used to test the hypothesis that there was no correlation between the primary (floristic) and secondary (environmental variables) matrices: *P* values were based on the proportion of 1000 Monte Carlo simulations with an eigenvalue greater than the observed eigenvalue. DCA and CCA were performed using MVSP multivariate (Kovach, 2004).

Results

The CA divided 77 floristic plots into three vegetation zones (Fig. 2). First vegetation zone comprised vegetation which is remnant of native scrub forest and was characterized mainly by trees and shrubs. Among trees *A. modesta*, *Acacia nilotica* and *Dalbergia sissoo* dominated in most of the sampling sites. Among shrubs *Lantana camara* was the most dominating specie whereas *Dodonea viscose* co-dominated in few plots. Other shrubs recorded were *Justicia adhatoda* and *Carrisa opaca.* In few sampling plots where tree cover was less, patches among shrubs were covered by two grass species viz., *Cynodon dactylon* and *Polypogon monospelinsis.* The soils were mostly sandy loam with rich organic matter, high nitrates and moisture contents, and slightly alkaline. Second vegetation zone was described as transition vegetation zone and dominated by *A. modesta D. sissoo*, *Morus* sp., *A. nilotica*, *L. camara*, *Zizyphus* sp., *C. opaca, P. roxbughii, J. adhatoda* and *B. papyrifera. B. papyrifera* was present either in scattered form or showed patchy distribution. Grasses such as *Desmostachya* sp., and *Bromus* sp., covers the ground where *Lantana camara* was absent. The soils were alkaline mainly loamy and sandy loam in texture. Third vegetation zone was identified as an invasive vegetation zone includes plots, which were dominated by *B. papyrifera* and where ground flora was absent except *Malvestrum* sp., *Cannabis sativa* and *Gallium* sp. Stunt growth of *L. camara* and *C. opaca* was observed in few sampling plots. The soils were with high organic matter and soil moisture contents and low species diversity in comparison to the other two vegetation zones.

DCA ordination performed using percentage cover of floristic data and vegetation zones identified using classification methods were overlaid on the DCA ordination of sites (Fig. 2a). DCA eigenvalues for the three axes were 0.31, 0.18 and 0.11 and explained 18.06%, 28.31% and 34.33% of species data variance along three axes (Table 1). In DCA ordination graph, along axis 1, two vegetation zones could be separated; one vegetation zone on the right end is dominated by *B. papyrifera* and vegetation zone two represented by transitional vegetation species whereas on the left end a vegetation zone is represented by native vegetation was found. Axis 1 was interpreted as organic matter and soil moisture gradient. These two variables increase from left to right along axis 1. Vegetation zone dominated by *B. papyrifera* and transitional vegetation required rich organic matter and soil moisture contents. These vegetation types are distributed on the negative side along axis 1 whereas native vegetation zone was distributed on the positive side. Along axis 2 transitional vegetation zone was separated when compared to other two vegetation zones which showed overlap. Native and transition vegetation zones were placed on positive end of axis 2 and native vegetation zone on the negative end. Axis 2 was interpreted as soil texture gradient. CCA identified soil organic matter, soil texture (proportion of % clay, % sand and % silt) as essential in relation to vegetation assemblages/zones (Monte Carlo permutation test, $p<0.05$) (Fig. 2b). These variables

explained a total of 39% variance in species data set. The CCA axis 1 was negatively correlated with organic matter (r= -0.42) and the axis 2 negatively correlated with % silt (r= -0.61) and % silt (r= -0.40), and positively with % sand (r= 0.60). The species and environmental correlation along three axes were 0.71, 0.67 and 0.71.

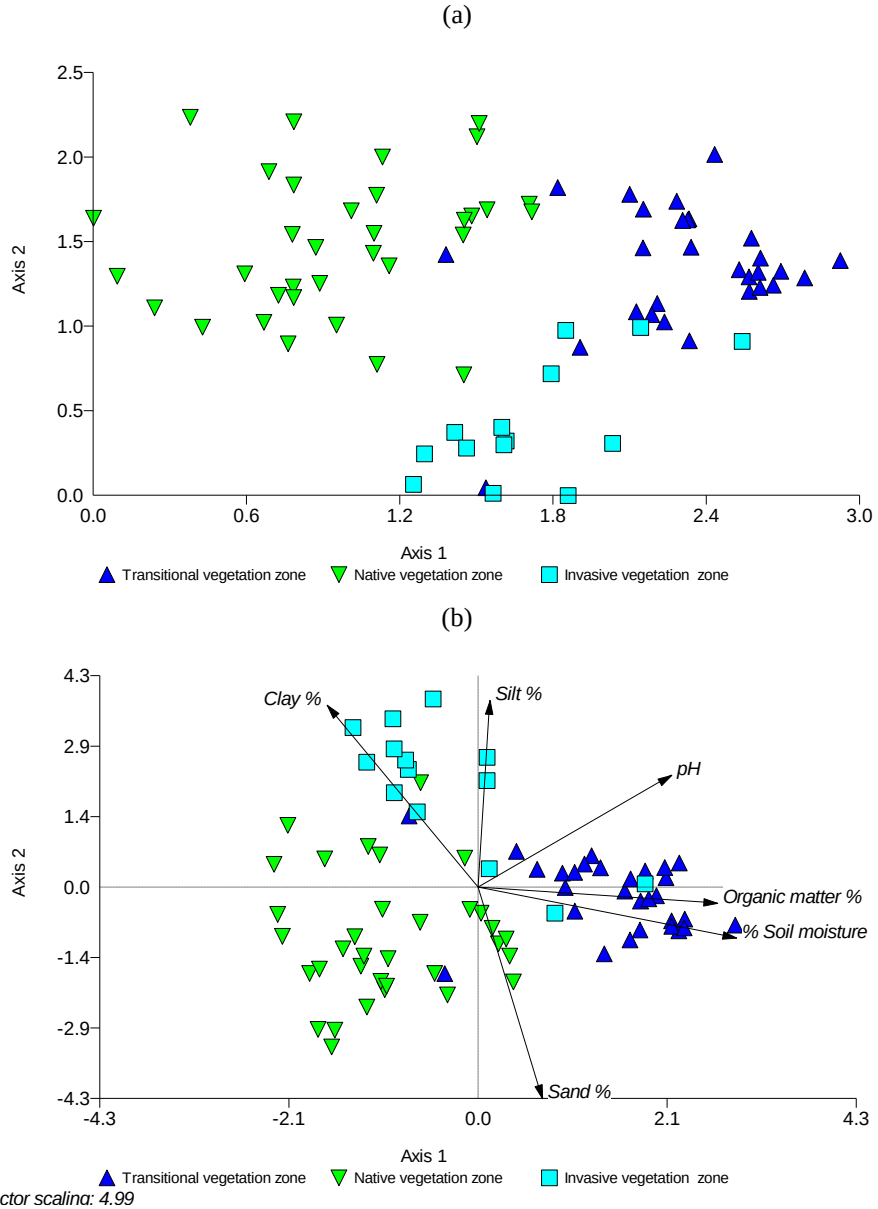

Fig. 2. DCA (a) and CCA (b) ordination plot showing the distribution of vegetation zones along two axes.

FA/PCA (raw varimax rotated) on the environmental data renders three factors (varifactors) with eigenvalues higher than 1.0 accounting for over 72% of total variance (Table 2). Varifactor 1 (VF1) is the most important with 33%of the total variance. VF1 shows three important soil parameters with loadings >0.70. As these three parameters could be associated with ''soil texture'' and considered as major contributor responsible for the adaptability and establishment of *B. papyrifera* in the study area which provides suitable soil for its growth and development. The second factor represents that organic matter and nitrate rich soils play very important role for its invasion. The third factor was weighted on elevation and soil moisture which represent that higher elevations and drier soils are not preferred by the invasive species. The VF2 and VF3 shows two parameters with loadings >0.70, they are soil organic matter and nitrates (VF2) and elevation and soil moisture (VF3) respectively.

Table 1. DCA and CCA ordination results.

	DCA			CCA		
	Axis 1	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**
Eigenvalues	0.31	0.18	0.10	0.32	0.22	0.16
Cum. Percentage of variation	18.06	28.31	34.33	8.15	14.43	16.62
Species environment Correlations*				0.71	0.67	0.71

*****Correlation between sample scores for an axis derived from the species data and the sample scores that are linear combinations of the environmental variables.

Table 2. Factor analysis of environmental variables.

Variables	**VF [a]1**	**VF [a] 2**	**VF 3 [a]**
Elevation (m)	0.043	-0.069	-0.649
% Soil moisture [b]	0.188	0.112	**0.844**
PH	-0.133	-0.425	0.467
Clay % [b]	**-0.840**	-0.164	-0.133
Silt % [b]	**-0.900**	0.104	0.028
Sand % [b]	**0.996**	0.010	0.045
Organic matter % [b]	-0.047	**0.861**	0.166
Nitrates (ppm) [b]	0.061	**0.831**	-0.023
Eigen value	2.630	1.670	1.480
% Total variance	32.830	20.900	18.460
Cumulative % variance	32.830	53.734	72.195

a VF (varifactor) = principal components factor from standardized data after varimax raw rotation. **b** Variables that have loadings (scores) >0.70. We have underlined the value in the VF where the associated variable presents such significant score.

Discussion

The analyses of this study showed that invasion by *B. papyrifera* in foothills of Himalaya were mainly associated with soil physiochemical properties and availability of soil moisture. Invasive vegetation zone dominated by *B. papyrifera* was correlated to soil physiochemical properties, suggesting that invasion success is insensitive to the topographic factors such as elevation. Species diversity in invasive vegetation zone was lower in comparison with native and transition vegetation zone suggesting that species diversity decreases with the dominance of *B. papyrifera* invasion which indicate that it is

a serious threat to natural vegetation and floral diversity as it is replacing the native species of the scrub forest. Over 60% of the sampled plots have been completely invaded by this plant species indicating its successful adaptation due to climatic condition prevailing in the study area. These results are consistent with the finding of Malik & Husain (2006a, b). However, *B. papyrifera* was less extensive in the north and south facing slopes of Shakarparian as these slopes were rocky and drier that could hinder *B. papyrifera* growth. Native vegetation was dominated by *A. modesta* mostly at drier sites as compared to sites invaded by *B. papyrifera.* The dominance of *A. modesta* on driers sites is largely due to its fondness for and greater tolerance of relatively dry and exposed conditions. Malik & Husain (2006a) have stated that *A. modesta* dominated the scrub forest in the Himalayan foothills and is present on thin, shallow and dry soils and may overlie a great variety of geographical formations from limestone, shale and quartzites to crystalline rocks. It was observed that in and around Islamabad, *B. papyrifera* has changed the xerophytic vegetation to mesophytic vegetation (Malik & Husain, 2006b). The study has showed that the vegetation of the study site has been extensively modified by *B. papyrifera* invasion for example at lower altitudes in the MHNP the original flora has been completely degraded by woody invasive species like *B. papyrifera* which was introduced to the capital Islamabad from Japan in 1960 and is now widely naturalized in and around the city. At some places such as Marghazar, the American Embassy, the G-7 stream and the green belt of the G10, high density of *B. papyrifera* was observed. At higher altitudes in MHNP, at Chauki and along the Kogina stream, a large number of *B. papyrifera* plants have started spreading recently, which are real threat for the scrub forest vegetation of MHNP at higher elevation. It is suspected that in the near future, large areas will be colonized by this species.

This study highlights and considered this species as real threat to scrub forest floristic diversity because instead of small herbaceous vegetation such as *Malvestrum* sp., *Cannabis sativa* and *Gallium* sp, nothing else grows under the canopy of *Broussonetia papyrifera.* Moreover, the planting of this species has been problematic for the residents of Islamabad and nearby Rawalpindi city due to its rapidly spreading nature and producing large amount of pollen causing pollen-related allergies. Some 30 years ago, its seeds were sprayed from helicopter over Islamabad to make the capital green in a short duration (per. com. with Capital Development Authority, Environmental Directorate). It must be eradicated or its density must be reduced, otherwise it will completely take over the original flora, as it has done around the American Embassy, Shakerparian and around Rawal Dam. An invasion of *B. papyrifera* was also observed in the Lohibehr Wildlife Park in nearby city Rawalpindi by Malik & Husain (2006a). It is anticipated that it could spread quickly, as maximum moisture is available for its growth and would possibly replace the remaining native vegetation of the scrub forest. Filed plots near the Pakistan Museum of Natural History (PMNH) and Shakarparian slope, which join the Zero Point, were found with high density of *B. papyrifera* where vegetation is more or less undisturbed. It is very likely that this invasive species will progressively spread in other adjacent areas. The history of *B. papyrifera* invasion in the study area is brief (about 30 yr), and there is no data available which could suggest that how long dominant canopy individuals of *B. papyrefera* can/will survive. Judging from pattern of growth and capacity to re-growth from cut stumps (pers. obs.), invaded patches may persist for hundreds of years or more. Given *B. papyrifera* invasion success in other areas of Pakistan and the infeasibility of eradicating this species once it becomes common, it is

used as a cultivated tree for shade in nearby villages and Punjab Province (in particular) should be discouraged and trees bearing staminate catkins should be removed from areas where invasion appears imminent and a major cause of asthma and related allergies due to its pollen. Presently to environmentalist, Capital Development Authority (CDA) responsible for the Islamabad development and park managers of MHNP, the invasion of *B. papyrifera* is amongst the top major concern as it is invading native plant diversity and habitats.

Although this is preliminary investigation and it seems that a forest habitat is vulnerable to invasion. No cataloging of invasive species yet exits in Pakistan and there is no dataset available that could give information and impact of invasive species on the future species composition and diversity of the scrub forest in the study area. Due to the slow growth of scrub forest species in comparison to this species and suitable physiochemical properties of the soil and availability of soil moisture may provide ample opportunity for *B. papyrifera* to gain a foothold in the study area. Assuming some upper limit of resource availability (such as high soil moisture and organic content and shady places), increased cover by exotic species may put some native species at a disadvantage as exotic species sequester resources. This sets the stage for the local replacement of native species by exotic species. Given current patterns of invasion, native plant species will be particularly difficult to protect in the study area. The CDA must consider the remedial measures to control its further spread and the biological control would be the better option along with the selective cutting of male plants.

It would suggest that soil edaphic parameters such as soil texture, soil moisture and organic matter contents are important environmental gradients controlling spatial distribution of *B. papyrifera* that has obtained the dominance in the study area and replaced the native scrub forest plant specie. Invasion by *B. papyrifera* in the study area have negative affect on the species diversity of vegetation zones identified that put emphasis that the remnants of scrub forest patches should be integrally protected and future spread of this species should be monitored and controlled.

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