# MULTIVARIATE IMPACT ANALYSIS OF *PARTHENIUM HYSTEROPHORUS* INVASION ON ABOVE-GROUND PLANT DIVERSITY IN POTHWAR REGION OF PAKISTAN

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**Abstract.** Phytosociological studies help to understand extent of biological invasion. Multiple analyses of ecological parameters at different locations derive general explanations of impact on species diversity in plant communities. Current study assessed the impact of *Parthenium hysterophorus* (an annual weed of great significance in Pakistan and worldwide) invasion on native vegetation in Pothwar region of Pakistan. The approach used for the study was random samplings with two categorical factors: invaded and non-invaded under same habitat conditions. Differences in number of species (S), abundance (N), species richness (R), evenness (J'), Shannon diversity index (H') and Simpson index of dominance (λ) were compared between invaded and control plots by t-test series. Control plots harbored by average of 0.9 more species per 10 $m^2$. The control category was more diverse (H' = 1.73) than invaded category (H' = 1.53). The higher value of species richness in control plots shows the heterogeneous nature of communities and *vice versa* in invaded plots. The lower value of index of dominance in invaded plots shows less sample diversity than in the control ones. At multivariate scale, ordination (nMDS) and ANOSIM showed significant magnitude of differences between invaded and control plots in all sites. The most effected site by *Parthenium* invasion was Jhelum followed by Attock, Rawalpindi, Chakwal and Islamabad. The decrease in diversity indices in invaded over control sites indicated less productive plant communities due to *Parthenium* invasion. This makes *Parthenium* a candidate of consideration for appropriate control measures.
**Keywords:** *invasion impacts, diversity indices, multivariate analysis, diversity conservation, PRIMER*

## Introduction

There has been a rapid acceleration in the number and rate of plant invasions attributed to increased dispersal of exotics and expansion of disturbed habitats associated with rapid human population growth (Collier and Vankat, 2002). The introduction of invasive plants may change the structure and function of ecosystem, e.g., alterations in succession, species composition, biomass, net primary productivity and nutrient cycling (Charles and Dukes, 2007; Dassonville et al., 2008). Invasive species may also deplete available resources. Other studies have shown changes at population, community and landscape levels (Collier and Vankat, 2002; Qureshi et al., 2014). Consequently, studying the community level impacts of the invader identifies its


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potential effects and provides valued information for management and nature conservation strategies (Hejda et al., 2009).

Plant invasions deplete native species diversity, alter community composition and effect ecosystem processes thus cause ecological and economic imbalance (Kunzi et al., 2015). Exotic plants coexist in relative harmony in native habitat but competitively exclude neighbors in recipient communities. Various studies have provided data on the effects of exotic invasive plants on declining indigenous diversity and altering native community composition. These studies assumed different mechanisms that generate substantial invasion impacts. Among these processes are allelopathy, competition, and alteration of native ecosystem characteristics (Odat et al., 2011). Direct competition with native flora may result in monocultures of exotic species, e.g. *Parthenium hysterophorus* in Pakistan, Australia and India and *Psidium cattleianum* in Mauritius (Dogra et al., 2010). In different parts of the world, 80% of endangered species are threatened by alien invasive species (Pimentel et al., 2005).

*Parthenium* is an aromatic, annual herb native to Mexico, southern United States and South & Central America. It was inadvertently introduced to many countries and now has become a troublesome rangeland and agricultural weed in parts of Africa, Asia, Australia and the Pacific Islands (*Fig. 1*). Because of its status in the world, it is documented among world's top ten worst weeds (Tamado and Milberg, 2000; Khan et al., 2014). *P. hysterophorus* is assumed to move in to India along food grains trade in from USA. It then has spread to sub-continent (Nath, 1988). It is supposed to enter Pakistan via road links where automobiles cross at many places every day. In Pakistan, *Parthenium* weed was stated in the 1980s from Gujarat, Punjab (Razaq et al., 1994). Since then, it has spread rapidly all through to Islamabad, Punjab Province and parts of Khyber Pukhtunkhwa. *Parthenium* affects biodiversity, crop production and human and animal health (Shabbir, 2013). It grows in a range of habitats. Wide environmental adaptability, drought tolerance, photo and thermo-insensitivity, high seed production, small and light weighted seeds adept of long distance travel via water, wind, birds, animals and vehicles, longevity of seeds in soil seed banks, strong competition and allelopathy contribute to its invasiveness (Khan et al., 2014; Hassan et al., 2012; Shabbir and Bajwa, 2006).

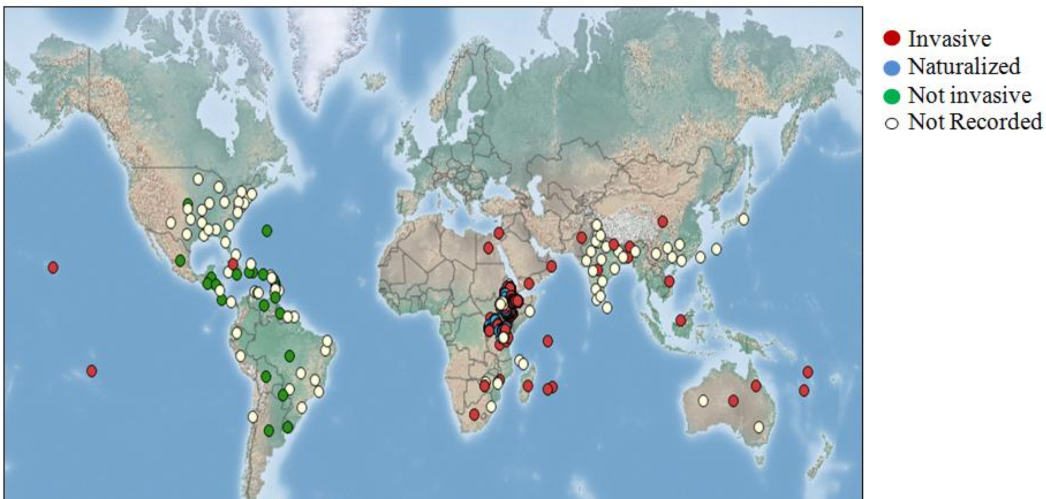


***Figure 1.*** *Distribution map and invasion status of Parthenium weed around the globe*


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*Parthenium* is one of the worst weeds presently known in Pakistan. No previous study is reported from Pothwar region regarding its ecological impacts. The current study was carried out to find out (1) what is the effect of *Parthenium* weed on ecological diversity indices in different districts of Pothwar region (assuming each district as 'site'); (2) do the effects on diversity differ between different sites (districts) in the area?

## Materials and methods

### Study area

Pothwar is a north-eastern plateau in Pakistan, making the northern part of Punjab. It edges Azad Kashmir (the western parts) and Khyber Pakhtunkhwa (southern parts). Pothwar Zone extends from 32.5°N to 34.0°N latitude and 72°E to 74°E longitude and lies between the Indus and Jhelum River. The plateau expanses from salt range northward to the foothills of Himalayas. The Pothwar region embraces Jhelum, Islamabad, Attock, Rawalpindi and Chakwal districts (*Table 1*). Total area of Pothwar region is 28488.9 km$^2$. (Rashid and Rasul, 2011). Pothwar region has an extreme climate with hot summers and cold winters. Weather is divided into four seasons: Cold (December-March); Hot (April-June); Monsoon (July-September) and Post-Monsoon season (October-November). This area gets an average annual rainfall of 812 mm, about half of which occurs in the Monsoon months (July-September). The mean maximum temperature rises till the month of June and then falls appreciably with advent of rains, being coldest in January (14.62-18.7 °C). Average temperatures range from 14 °C in January to 37 °C in June (*Fig. 2*). The region has broadly four types of soil: loess, river alluvium, residual and piedmont alluvium. Due to dynamic climate and combination of hills and plains, Pothwar region is rich in biodiversity. Native vegetation is characterized by open patches of grasses and forb species. *Albizia lebbeck* (L.) Benth., *Acacia modesta* Wall., *Abies pindrow* (Royle ex D. Don) Royle, *Cassia fistula* L., *Cedrela toona* Roxb. ex Rottler, *Dalbergia sissoo* Roxb., *Dodonaea viscosa* Jacq., *Ficus religiosa* L., *Ficus benghalensis* L., *Melia azedarach* L., *Olea cuspidata* Wall. Ex G. Don., *Zizyphus jujuba* Mill. and *Zizyphus nummularia* (Burm. f.) Wight & Arn. are principle species in the region (Shabbir et al., 2012; Ghufran et al., 2013).

***Table 1.*** *Coordinates of study sites*

| District | Coordinates |
|---|---|
| Jhelum | 32.94°N, 73.72°E |
| Islamabad | 33.73°N, 73.09°E |
| Attock | 33.76°N, 72.36°E |
| Rawalpindi | 33.59°N, 73.04°E |
| Chakwal | 32.93°N, 72.85°E |

### Experimental design

Field work was carried out during July-August (being the maximum growth period of plants), 2016. The effect of invasion was studied in each of five districts (Attock, Chakwal, Jhelum, Islamabad and Rawalpindi). Ecological indices for selected invaders


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were calculated and compared at various sites. The sampling technique was random. For each district six invaded and six non-invaded paired vegetation plots (each 3.16 × 3.16 m in size, i.e., 10 $m^2$ in area) were sampled. Based on visual observations, plot of invaded vegetation (‘invaded plot’) where the invader showed dominance was considered as ‘treatment’ and a second vegetation plot, usually 0.5-1 km apart from treatment, where invader has no dominance (‘non-invaded plot’) was considered as the “control”. The estimated density of the weed in the area across locations was 4/$m^2$. In all, a total of 60 vegetation plots were sampled (consisting of six paired samples per district, and hence 30 treatments; 30 controls for the entire Pothwar region) (*Fig. 3*). Within each randomly chosen plot (10 $m^2$ in area), all vascular plant species in control and invaded plots were identified to species level.

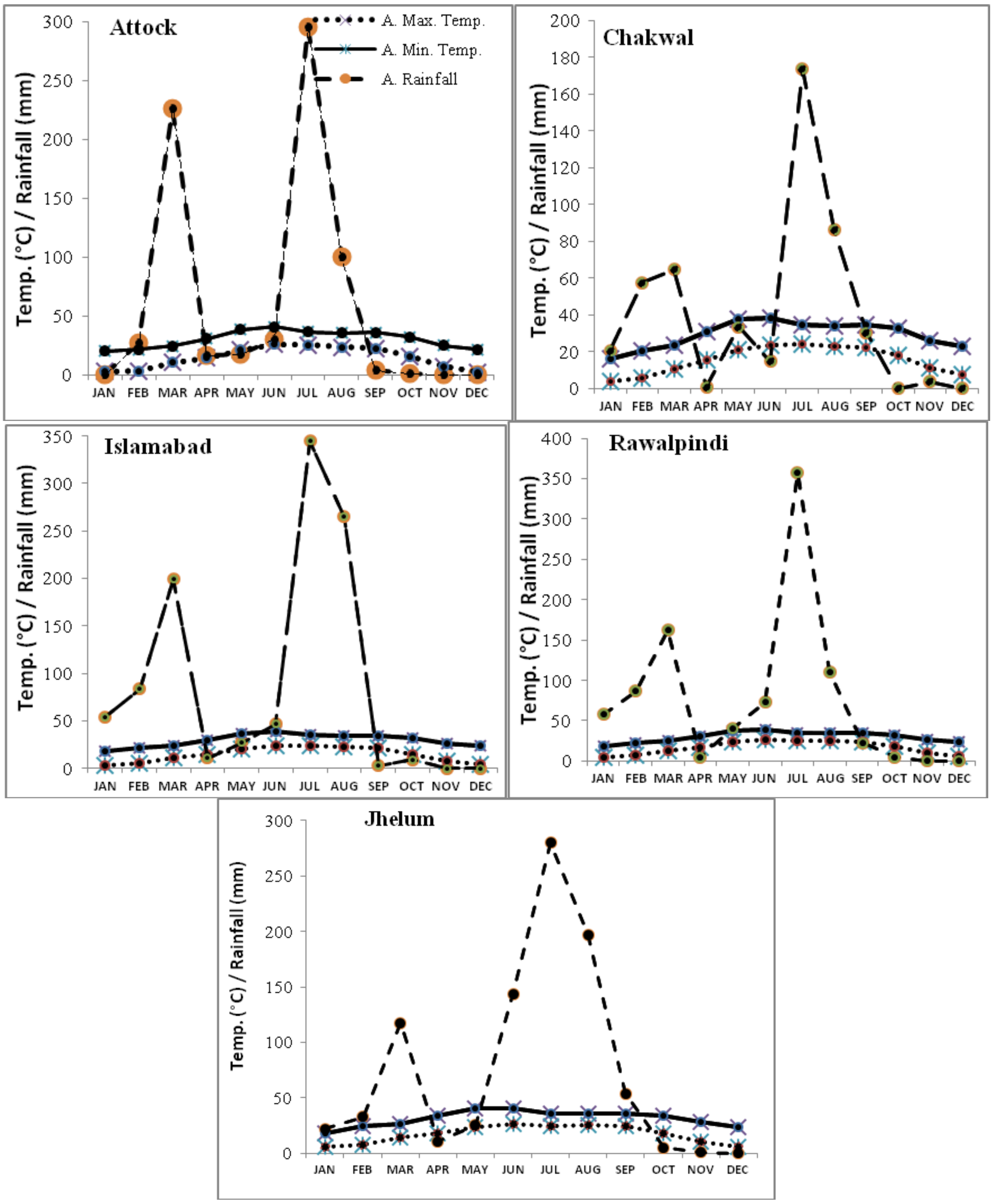


***Figure 2.*** *Mean monthly climate data of Pothwar region, Pakistan for year 2017. (Data sourced from Pakistan Meteorological Department University Road Karachi, Pakistan)*


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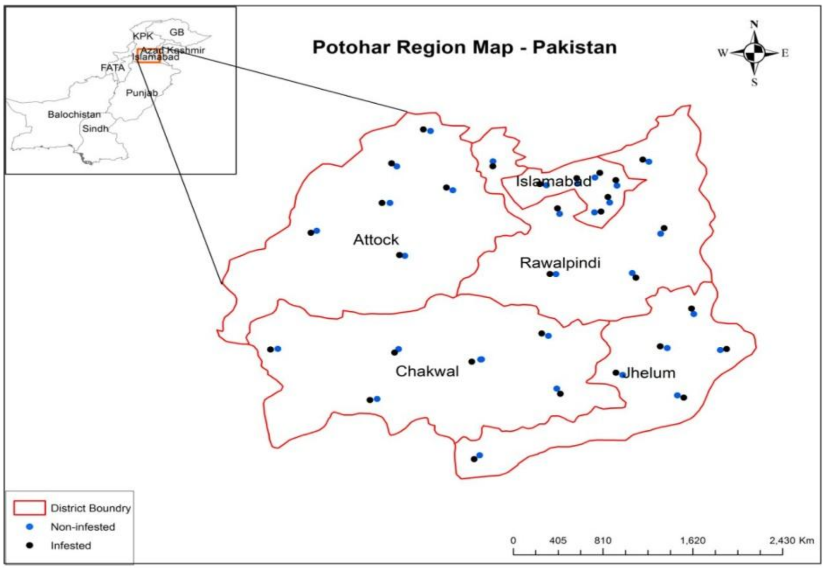


***Figure 3.*** *Distribution of plots for impact analysis of Parthenium hysterophorus in Pothwar region*

## *Data analyses*

Species frequency data were created and invasion impacts of *P. hysterophorus* on local flora were assessed by calculating and comparing ecological indices including Margalef's index of richness, Shannon–Weaver index of diversity, Simpson index of dominance and index of evenness for control and invaded sites (Magurran, 1998). These parameters were calculated as (*Eqs. 1*, *2*, *3* and *4*):

$$\text{Margalef's index of richness (R)} = \frac{S-1}{\ln N} \qquad \text{(Eq.1)}$$

N = Total number of individuals; S = Total number of species.

$$\text{Shannon-Weaver index of diversity } (H') = -\sum_{i=1}^{S}\left(\frac{n_i}{N} \times ln\frac{n_i}{N}\right) \qquad \text{(Eq.2)}$$

N = Total number of individuals of all species; n = Actual number of individuals of one species.

$$\text{Simpson index of dominance } (\lambda) = 1 - \frac{\sum_{i=1}^{S} n_i(n_i-1)}{N(N-1)} \qquad \text{(Eq.3)}$$

N = Total number of individuals of all species; n = Number of individuals of one species.

$$\text{Index of evenness } (E) = \frac{H'}{lnS} \qquad \text{(Eq.4)}$$

H' is Shannon's index; S = Number of species.


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Rarefaction curves were plotted to determine if sampling was adequate in each district using observed, Coleman's, Jackknife, Bootstrap and Chao2 models in PRIMER v. 7 (Clarke and Warwick, 2001). All gave comparable results; consequently only that of real (observed) data are presented. Data were then subjected to univariate and multivariate analyses of non-metric multidimensional scaling procedure (Clarke and Gorley, 2015). Data were log transformed to achieve criteria of normality (evenness and Simpson index of diversity). For invasion impact analysis, diversity indices including total number of species (S), abundance (N), species richness (R), species evenness (J'), Shannon index of diversity (H′) and Simpson index of dominance (λ) were calculated for control as well as for invaded plots. The above ecological indices were subjected to analysis of variance (ANOVA) with invasion status and districts as factors using IBM SPSS v. 21. Differences between ecological indices for five districts were individually tested for significance between invaded and control plots by multiple comparisons tests of t-test. Data were further analyzed for species assemblages by non-metric multidimensional scaling (nMDS) in two-three dimensions with invasion status (control, invaded) as factor using PRIMER V.7 software. nMDS was used to ordinate the similarity of data between site categories (invaded, control) based on Bray-Curtis dissimilarity matrix following log-transformation of species abundance data due to zero species count in some plots. The range of clustering of sites and locations in response to invasion were assessed by analysis of similarity (ANOSIM) and similarity percentage (SIMPER). ANOSIM relates mean difference of ranks between and within groups, generating the Global statistic (R). The values of Global statistic (R) range from -1 to +1. Values near 0 and negative values demonstrate similarity among groups. Values impending +1 indicate a strong dissimilarity among groups (Clarke and Warwick, 2001; Osunkoya et al., 2017). SIMPER identified species contributed most to average dissimilarity between groups (invaded and control plots). This technique calculates average impact of each species contributing to dissimilarity between groups (Clarke and Warwick, 2001). Values of percentage similarity between groups range between 0 to 100, with 100 stating maximum similarity.

## Results

To assess sampling completeness, rarefaction curves plotting cumulative number of species as a function of sampling effort were used which indicated that sampling was reasonably complete (*Fig. 4*). A total of 56 plant species from 50 genera were documented during the study (*Table 2*). A total of 56 species were recorded in control plots compared with 37 in infested plots. Mean species diversity and richness/quadrat was higher in control plots (*Fig. 5*).

***Table 2.*** *Plant species found in studied plots, family and life form*

| S# | Plant species | Family | Life form |
|---|---|---|---|
| 1 | *Achyranthes aspera* L. | Amaranthaceae | Herb |
| 2 | *Anagallis arvensis* L. | Primulaceae | Herb |
| 3 | *Argemone mexicana* L. | Papaveraceae | Herb |
| 4 | *Amaranthus viridis* L. | Amaranthaceae | Herb |
| 5 | *Astragalus scorplurus* Bunge. | Papilionaceae | Herb |
| 6 | *Bellis perennis* L. | Asteraceae | Herb |
| 7 | *Broussonetia papyrifera* (L.) L'Herit. ex Vent. | Moraceae | Tree |


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| S# | Plant species | Family | Life form |
|---|---|---|---|
| 8 | *Calotropis procera* Br. | Asclepiadaceae | Shrub |
| 9 | *Cannabis sativa* L. | Cannabaceae | Herb |
| 10 | *Cenchrus biflorus* Roxb. | Poaceae | Grass |
| 11 | *Chenopodium ambrosioides* L. | Chenopodiaceae | Herb |
| 12 | *Circium arvense* L. | Asteraceae | Herb |
| 13 | *Convolvulus arvensis* L. | Convolvulaceae | Herb |
| 14 | *Cynodon dactylon* L. (Pers.) | Poaceae | Grass |
| 15 | *Datura alba* Nees | Solanaceae | Shrub |
| 16 | *Datura innoxia* Miller | Solanaceae | Shrub |
| 17 | *Dicanthium annulatum* Stapf. | Poaceae | Grass |
| 18 | *Digitaria ciliaris* (Retz.) Koeler | Poaceae | Grass |
| 19 | *Erianthus munja* L. | Poaceae | Grass |
| 20 | *Fumaria indica* (Hausskn.) Pugsley | Fumariaceae | Herb |
| 21 | *Impatiens edgeworthii* Hook. f. | Balsaminaceae | Herb |
| 22 | *Lathyrus aphaca* L. | Papilionaceae | Herb |
| 23 | *Malvestrum coromandelianum* (L.) Garcke | Malvaceae | Herb |
| 24 | *Medicago polymorpha* L. | Papilionaceae | Herb |
| 25 | *Poa annua* L. | Poaceae | Grass |
| 26 | *Portulaca oleracea* L. | Aizoaceae | Herb |
| 27 | *Prosopis cineraria* (Linn.) Druce | Mimosaceae | Tree |
| 28 | *Prunella vulgaris* L. | Labiateae | Herb |
| 29 | *Ranunculus muricatus* L. | Ranunculaceae | Herb |
| 30 | *Ricinus communis* L. | Euphorbiaceae | Shrub |
| 31 | *Rosa brunonii* Lindl. | Rosaceae | Shrub |
| 32 | *Rosa damascena* Mill. | Rosaceae | Shrub |
| 33 | *Rumex hastatus* D. Don | Polygonaceae | Shrub |
| 34 | *Rumex dentatus* L. | Polygonaceae | Herb |
| 35 | *Saxifragra androsacea* L. | Saxifragaceae | Herb |
| 36 | *Silybum marianum* (L.) Gaertn. | Asteraceae | Herb |
| 37 | *Solanum incanum* L. | Solanaceae | Shrub |
| 38 | *Solanum miniatum* Beruh. ex Willd. | Solanaceae | Herb |
| 39 | *Solanum surattense* Burm. F. | Solanaceae | Shrub |
| 40 | *Solanum nigrum* L. | Solanaceae | Herb |
| 41 | *Sonchus asper* (L.) Hill | Asteraceae | Herb |
| 42 | *Sorghum halepense* L. | Poaceae | Grass |
| 43 | *Suaeda fruticosa* Forsk. | Amaranthaceae | Shrub |
| 44 | *Swertia paniculata* Wall. | Gentianaceae | Herb |
| 45 | *Taraxacum officinale* (L.) Weber ex F.H. Wigg | Asteraceae | Herb |
| 46 | *Tamarix aphylla* (L.) Karst. | Tamaricaceae | Tree |
| 47 | *Tephrosia purpurea* (Linn.) Pers. | Papilionaceae | Herb |
| 48 | *Tinospora cordifolia* Miers ex Hook. f | Menispermaceae | Herb |
| 49 | *Tribulus terrestris* L. | Zygophyllaceae | Herb |
| 50 | *Urtica dioica* L. | Urticaceae | Herb |
| 51 | *Withania somnifera* L. (Dunal) | Solanaceae | Shrub |
| 52 | *Zizyphus mauritiana* Lamk. | Rhamnaceae | Shrub |
| 53 | *Capsella bursa-pestoris* (L.) Medik. | Brassicaceae | Herb |
| 54 | *Cyperus rotundus* L. | Cyperaceae | Sedge |
| 55 | *Polygonum plabegem* R. Br. | Polygonaceae | Herb |
| 56 | *Eclipta prostata* L. | Asteraceae | Herb |

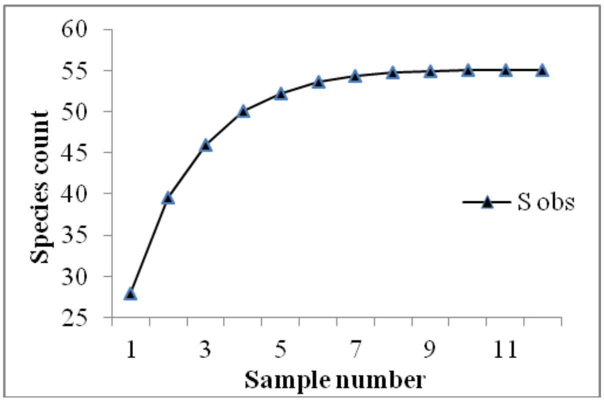


***Figure 4.*** *Rarefaction curve showing cumulative number of species recorded as a function of sampling effort*

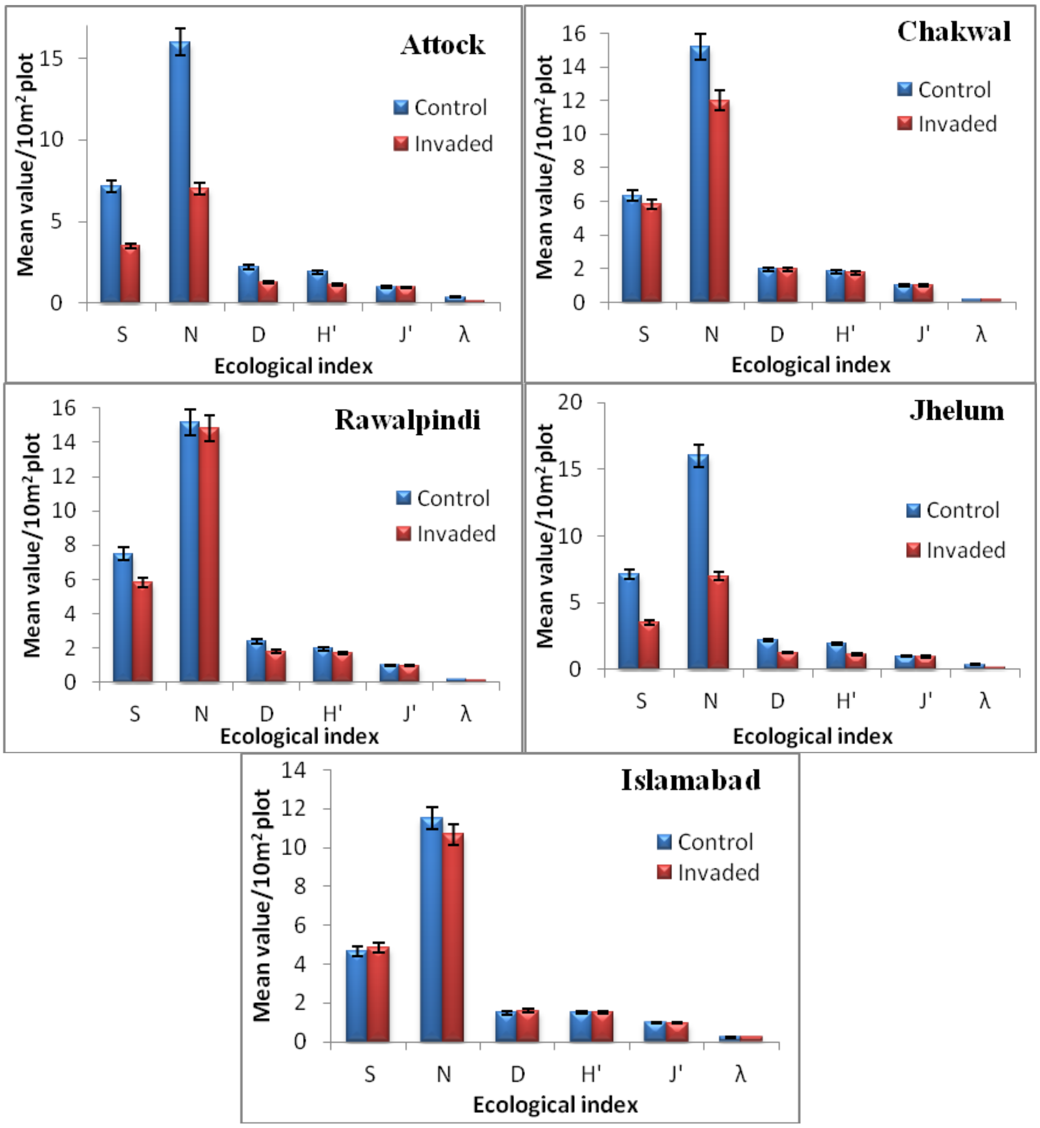


***Figure 5.*** *Mean values/10 m$^2$ for ecological indices of invaded vs control plots in different sites. (S = Number of species; N = Abundance; D = Species richness; H' = Shannon index of diversity; J' = Species evenness; λ = Simpson index of dominance)*


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Comparisons of ecological indices showed significant difference across districts and invasion status. *Parthenium* invasion exhibited variable impact across five districts by reducing species number per plot (S) and abundance (N) up to a maximum of 40% in Attock. Control plots harbored on average 6.033 ± 1.75 (mean ± SD, n = 30) species. This was greater than that observed in the invaded plots (5.133 ± 1.83) and the difference was statistically significant (t = 2.09, df = 29, p = 0.045). A total of 181 and 154 individuals were recorded in control and invaded plots respectively. Similarly, abundance in control and invaded plots differed by 3.7 ± 3.83 (mean±SD, n = 30) and the difference was significant (t = 4.34, df = 29, p < 0.0001). Control plots also exhibited higher values of species richness by a difference of 0.15 ± 0.51, species evenness by 0.019 ± 0.02; Shannon index of diversity by 0.2 ± 0.34 and Simpson index of dominance by 0.22 ± 0.35 (*Table 3*).

***Table 3.*** *Analysis of variance (ANOVA) of invasion impacts and district on diversity indices of local plant community*

| **Ecological index** | **SUMMARY ANOVA** | | | **Mean (±SD)** | |
|---|---|---|---|---|---|
| | **District (D)** | **Invasion status (IS)** | **D$^x$IS interaction** | **Control (30)** | **Invaded (30)** |
| No. of species (S)/10 $m^2$ | ** | ** | *** | 6.033±1.75 | 5.133±1.83 |
| Abundance (N)/10 $m^2$ | ** | *** | ** | 14.4±3.81 | 10.70±3.86 |
| Species richness (R) | ** | NS | *** | 1.87±0.49 | 1.62±0.53 |
| Species evenness (J') | NS | ** | NS | 0.028±0.039 | 0.009±0.006 |
| Shannon index of diversity (H') | ** | ** | *** | 1.73±0.29 | 1.53±0.406 |
| Simpson index of dominance (λ) | ** | ** | *** | 1.72±0.29 | 1.50±0.42 |

*******P ≤ 0.001; ******P ≤ 0.02; *P ≤ 0.05; NS (not significant) P > 0.05

For individual district, native flora differed significantly in species density (S), abundance per plot (N), species evenness (J') and Simpson index of dominance (λ) but not in overall species richness (R) and Shannon index of diversity (H'). *Parthenium* invasion had significant impacts on all ecological indices except species richness (R) at site 1 (Attock). For site 2 (Chakwal), only abundance was affected significantly. For site 3 (Islamabad) invasion impacts were not significant only on native species abundance. Species evenness (J') was non-significant for site 4 (Jhelum) while for site 5 (Rawalpindi) the only index significantly affected by *Parthenium* invasion was species evenness (J') (*Table 4*).

***Table 4.*** *Student's t-test for significance of differences between control and invaded plots at different sites*

| **Site** | **Number of species (S)** | **Abundance (N)** | **Species richness (D)** | **Species evenness (J')** | **Shannon index of diversity (H')** | **Simpson index of dominance (λ)** |
|---|---|---|---|---|---|---|
| Attock | * | ** | NS | * | ** | * |
| Chakwal | NS | * | NS | NS | NS | NS |
| Rawalpindi | ** | NS | ** | ** | ** | ** |
| Jhelum | *** | ** | ** | NS | ** | ** |
| Islamabad | NS | NS | NS | *** | NS | NS |

*******P ≤ 0.001; ******P ≤ 0.02; *P ≤ 0.05; NS (not significant) P > 0.05

The ordination (nMDS) and ANOSIM showed significant magnitude of differences between species composition of invaded and control plots in all sites with global R values of 0.876 ($p = 0.002$), 0.519 ($p = 0.002$), 0.598 ($p = 0.002$), 0.907 ($p = 0.002$) and 0.759 ($p = 0.002$) for Attock, Chakwal, Islamabad, Jhelum and Rawalpindi, respectively (*Fig. 6*). The greatest dissimilarity between invaded and control plots was noticed by Jhelum.

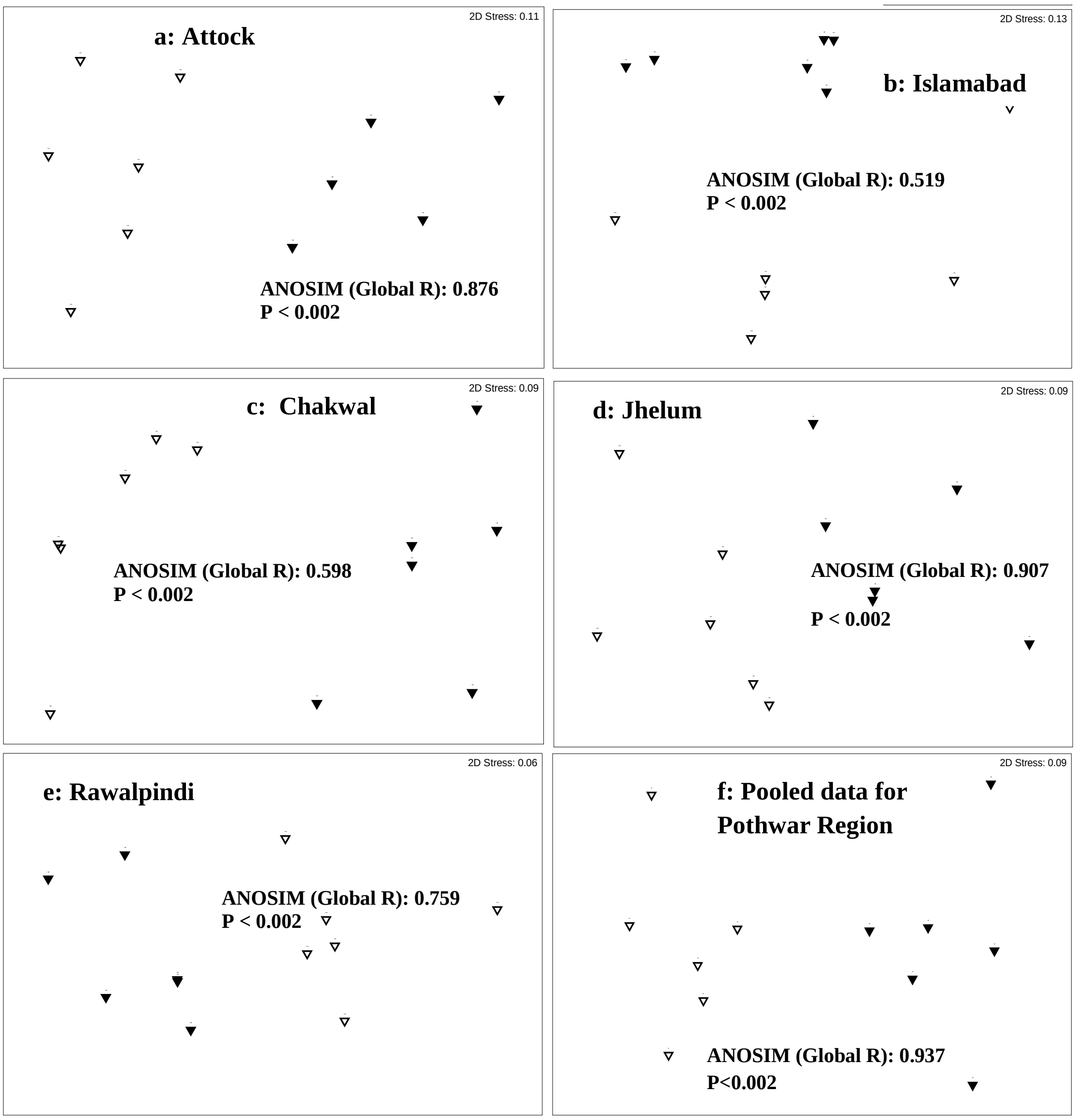


***Figure 6.*** *Multidimensional scaling (MDS) ordination and analyses of similarity (ANOSIM) results of invasion status data for Pothwar region, Pakistan (open symbols are for control, uninvaded plots, and closed symbols are for invaded plots)*

Similarity percentage (SIMPER) analysis of data suggested those species contributing most to average dissimilarity between control and invaded groups. This analysis also computed average contribution of species causing dissimilarity. Few top species separating invaded plots from non-invaded plots (control) for analysis are enlisted in *Table 5*. *Tephrosia purpurea* and *Lathyrus aphaca* were found in control


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plots while they were not observed in invaded plots, whereas a grass species (*Poa annua*), and broad leaf species like *Solanum*, *Ricinus* and *Taraxacum* were conspicuously displaced in *Parthenium* invaded plots.

***Table 5.*** *SIPMER analysis of Parthenium invaded and control sites in Pothwar region, Pakistan. Data have been pooled prior to analyses across districts*

| Average dissimilarity = 60.14% | | | | | |
|---|---|---|---|---|---|
| Average abundance | | | | | |
| **Species** | **Control** | **Invaded** | **Av. Diss.** | **Diss./SD** | **Contribution (%)** |
| *Poa annua* L. | 2.94 | 0.00 | 2.38 | 8.06 | 3.95 |
| *Lathyrus aphaca* L. | 0.00 | 2.69 | 2.18 | 5.82 | 3.63 |
| *Solanum miniatum* L. | 2.47 | 0.00 | 2.00 | 7.85 | 3.32 |
| *Ricinus communis* L. | 2.19 | 0.00 | 1.77 | 2.05 | 2.95 |
| *Convolvulus arvensis* L. | 1.80 | 1.79 | 1.49 | 1.32 | 2.48 |
| *Taraxacum officinale* (L.) Weber ex F.H. Wigg | 1.77 | 0.00 | 1.40 | 2.07 | 2.32 |
| Rosa *damascena* Mill. | 1.82 | 0.18 | 1.38 | 1.41 | 2.29 |
| *Tribulus terrestris* L. | 1.62 | 0.00 | 1.31 | 2.03 | 2.18 |
| *Fumaria indica* (Hausskn.) Pugsley | 2.35 | 1.15 | 1.31 | 1.55 | 2.18 |
| *Tephrosia purpurea* (L.) Pers. | 0.00 | 1.63 | 1.29 | 1.36 | 2.15 |
| *Portulaca oleracea* L. | 1.94 | 1.10 | 1.26 | 2.37 | 2.10 |
| *Circium arvense* L. | 1.63 | 0.00 | 1.25 | 1.69 | 2.08 |
| *Saxifragara sndrosacea* L. | 1.73 | 0.54 | 1.24 | 1.51 | 2.06 |
| *Anagallis arvensis* L. | 2.67 | 1.49 | 1.24 | 1.24 | 2.06 |
| *Tinospora cordifolia* Miers ex Hook. f. | 1.52 | 0.00 | 1.23 | 1.90 | 2.04 |
| *Solanum nigrum* L. | 1.87 | 0.86 | 1.21 | 1.92 | 2.02 |
| *Saxifragra androsacea* L. | 1.51 | 0.00 | 1.19 | 1.34 | 1.97 |
| *Tamarix aphylla* (L.) Karst. | 1.39 | 0.40 | 1.15 | 0.96 | 1.91 |
| *Solanum incanum* L. | 1.74 | 1.04 | 1.12 | 1.56 | 1.87 |
| *Eclipta prostata* L. | 1.95 | 1.02 | 1.12 | 1.25 | 1.86 |

Values are average abundance ranking (1-rare; 2-common; 3-very common; >4-dominant)

## Discussion

*Parthenium* weed exerts significant impact on natural communities by displacement of native species and hence exert discrepancy in natural ecosystems. This discrepancy results in formation of its large monocultures. In present study, comparisons of ecological indices across invaded and control plots indicated significant differences in the study area. These findings are in-line with other studies on this alien invasive weed, in which indicated strong effects of the invader on ecosystem properties, e.g., in grazing and wastelands of district Attock (Riaz and Javaid, 2011), district Hafizabad, (Riaz and Javaid, 2010) and Islamabad, Pakistan (Shabbir and Bajwa, 2007).

The results show modifications in vegetation composition of invaded and control plots. Analysis of variance among invaded and control plots showed significant decrease in ecological indices across site and invasion status. These results are consistent with other studies on invasive species indicating their negative effects on bio-diversity and ecosystem properties (Manchester, 2000; McNeely, 2001; Grice, 2006;


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Borokini et al., 2011; Jeschke et al., 2014; Panetta and Gooden, 2017). In our study, despite the negative effect of *P. hysterophorus* on species composition, species evenness of control and invaded plots was not significantly different. That is contradiction to above-mentioned studies; however, a few studies have shown that invasive species pose little or no effect on species diversity (e.g., Martin, 1999; Hejda and Pysek, 2006; Timsina et al., 2011). It is reported elsewhere that *Parthenium* invasion enriches compositional diversity but may result in extinction of native species (Nigatu and Sharma, 2013).

Wide environmental adaptability, drought tolerance, photo and thermo-insensitivity, high seed production and short life cycle (being an annual), small and light seeds capable of long distance travel via water, wind, birds, animals and vehicles, longevity of seeds in soil seed banks, strong competition and allelopathy contribute to the invasiveness of Parthenium weed (Shabbir and Bajwa, 2006; Hassan et al., 2012; Khan et al., 2014). Allelopathy especially plays important role in the invasion of this weed. The major allelopathic compounds found in *P. hysterophorus* are, gentisic, o-coumaric, p-coumaric, ferulic, vallinic, caffeic, salicylic acid, p-hydroxybenzoic and trans-cinammic acids and sesquiterpene lactone etc. (Borah et al., 2016). These allelochemicals are supposed to reduce native seed germination, allowing the weed to pre-empt space and establish monocultures.

*Parthenium* invasion exhibited variable impacts in five sites by reducing species number per plot (S), abundance (N), species richness (R), species evenness (J'), Simpson index of dominance (λ) and Shannon index of diversity (H'). The trend of decrease in ecological indices in invaded plots is similar to invasion studies on *P. hysterophorus* from Australia, Ethiopia, Nigeria, Tanzania and India (Grice, 2006; Kilewa and Rashid, 2012; Seta et al., 2013; Borokini et al., 2011; Abdulkerim-Ute and Legesse, 2016). The most effected site by *Parthenium* invasion was Jhelum followed by Attock, Rawalpindi, Chakwal and Islamabad. The lowest invasion impacts in Islamabad compared to other sites are probably because of management practices in the area being its importance as metropolitan region of Pakistan while highest dissimilarity in invaded and control plots in Jhelum is possibly due to the saline soil of the area (Anonymous, 2017).

The ordination (nMDS) and ANOSIM showed significant magnitude of differences between species assemblages of invaded and control plots. The difference was significant for all of five study sites but the greatest dissimilarity between invaded and control plots were noticed by Jhelum. It was reported that the *Parthenium* plant has a higher survival rate in higher level of soil salinity (Upadhyay et al., 2013), a condition inimical to establishment of many native plant species. Consequently the higher invasion impacts in Jhelum are possibly due to its saline soil (Anonymous, 2017).

SIMPER analysis showed dominance of fewer species in invaded plots than in control. These were *Tephrosia purpurea* and *Lathyrus aphaca.* Possible reason for their presence in invaded plot may be due to their aggressive nature as weeds in their own right. Perhaps higher contribution values of Fabaceae weeds is due to competition potential with *Parthenium* as suggested by Belachew and Tessema (2015); Gnanavel (2013). There is an urgent need of appropriate control measures including the use of proven biological control agents for this weed in Pakistan as done elsewhere around the globe/world, e.g., Australia and South Africa (Kaur et al., 2014; Strathie et al., 2011).


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## Conclusion

The increased occurrence of invasion around the world poses a major threat to indigenous diversity. Plant invasions in novel areas deplete species diversity, alter indigenous community composition, affect ecosystem processes and thus cause huge ecological and economic imbalance. Invasive species studied in the past revealed that the effects of invasion are complex and can permanently alter the function and structure of communities, cause local annihilations and changes in ecosystem processes. Invasion by alien plant species affect the composition and dynamics of species on a wide scale and have great impact on ecosystem functions. The decrease in ecological diversity indices in invaded over control sites in present study indicated that plant communities become less productive due to *Parthenium* invasion, hence it is a threat to plant diversity of invaded areas. There is an urgent need of appropriate control measures including the use of proven biological control agents for this weed in Pakistan.

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