



## Article

# Invasive Milk Thistle (*Silybum marianum* (L.) Gaertn.) Causes Habitat Homogenization and Affects the Spatial Distribution of Vegetation in the Semi-Arid Regions of Northern Pakistan

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**Abstract:** Global biodiversity management is of concern due to invasive plant species that dramatically disturb the native communities causing biological homogenization. Therefore, the present research investigated the impacts of *Silybum marianum*, an aggressive invasive alien species, on communities' diversity and environmental variables in Khyber Pakhtunkhwa, Pakistan. Phytosociological characteristics and diversity indices of the communities were sampled in seventy-five sites using the quadrat method. These sites were categorized based on invasion intensities, i.e., fully invaded sites with a 100% importance value index of the selected species, severely invaded sites with >60% of IVI, and partially invaded sites with >30% of the chosen species. The community composition significantly changes with changes in invasion intensity. Similarly, *S. marianum* invasion has a pronounced impact on the community's diversity showing significant differences among the three categorized groups ( $p < 0.05$ ). The canonical correspondence analysis revealed 29.9% variance where soil texture, nutrients, and elevations were influential variables in maintaining the community's structure and composition. The study concludes that *S. marianum* dominated well-established communities in the existing soil and environmental variables; therefore, it was found to be influential in disturbing the native communities and may severely harm the crop plant and agricultural system in the future.

**Keywords:** alien invasive species; *Silybum marianum*; environmental variables; vegetation structure; spatial distribution



**Citation:** Khan, N.; Ullah, R.; Ali, K.; Jones, D.A.; Khan, M.E.H. Invasive Milk Thistle (*Silybum marianum* (L.) Gaertn.) Causes Habitat Homogenization and Affects the Spatial Distribution of Vegetation in the Semi-Arid Regions of Northern Pakistan. *Agriculture* **2022**, *12*, 687. <https://doi.org/10.3390/agriculture12050687>

Academic Editors: Kirill A. Zhichkin and Arthur A. Gibadullin

Received: 4 April 2022

Accepted: 26 April 2022

Published: 12 May 2022

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## 1. Introduction

The biological invasion of alien plant species is the most critical and challenging threat presented to native biodiversity researchers [1]. The purposeful and accidental transfer of species is facilitated by human activities, the development of transportation facilities, and increased population mobility and migration [2]. Several invasive species have been introduced for various purposes, including agriculture, forestry, and ornamentation [3]. However, invasive plant species have dramatically affected native plant communities and ecological processes, having varying impacts on different habitats [4]. Although plant invasions seldom result in biodiversity loss, several studies [5] have indicated significant biodiversity losses due to invasive species establishment in an area [6]. Plant invasions may change an ecosystem's biodiversity, speed up the nutrient cycle process, and impact the natural environment and human well-being [7]. The uniformity of plant ecosystems at different geographical scales has also been linked to species invasion [8].

Alien plant species may be found in various environments, including roads, railway lines, and urban and rural regions, resulting in community homogeneity [9]. The alteration

of various populations within a region to become increasingly similar is known as biotic homogenization [10]. They are considered a valuable resource because of their ability to adapt to new environmental conditions and modify native plant populations [11]. Despite biotic and abiotic restrictions, an invasive species may be able to invade and expand in a new environment [12]. Invasive plants are successful for several reasons, including producing large numbers of viable seeds, repelling herbivores, surviving in various environments, tolerating high stress levels, and swiftly regenerating from seeds, stems, or roots. They must exhibit these features to flourish, propagate, and ultimately wreak havoc on their natural ecosystem [13].

Milk thistle (*Silybum marianum* (L.) Gaertn.), hereafter *S. marianum*, is an annual or biennial herb of Asteraceae. The species is native to the southeast coast of England and has been widely introduced outside of its native range, including North America, Iran, Australia, and New Zealand, where it is considered an invasive weed [14]. The milk thistle may be annual, winter, or biannual [15]. The plant now spreads in most of the world's temperate regions [16] and has broad leaves that grow to 200–250 cm [17]. Even though milk thistle is commonly grown as a medical plant in Egypt, Europe, Argentina, and China, several countries have labeled it a noxious pest [18]. In Africa, North and South America, the Middle East, and Australia, *S. marianum* is a prevalent weed [19]. After establishing itself, the plant becomes a competitive invasive species, developing large, thick patches that shade other plants and compete for water and nutrients [20]. It is termed ruderal or weedy because it grows in dense clusters along roadsides and wastelands [21].

It has become an invasive weed in Pakistan's northern irrigated areas, causing havoc on crops including *Triticum aestivum* L. (wheat), *Trifolium alexandrinum* L. (berseem clover), *Hordeum vulgare* L. (barley), *Avena sativa* L. (oat), and *Saccharum officinarum* L. (sugar cane) [22]. Due to the lack of pesticides and understanding about weed management along roadsides and irrigation systems in the area, this species is exceedingly competitive and emerges simultaneously with or before winter crops. In KP, Pakistan, wild oat (*Avena fatua* L.) and tiny seed canary grass (*Phalaris minor* L.) are the most common weeds. During the preceding decade, clodinafop and fenoxaprop-P were regularly employed to manage these grass weeds, perhaps opening a door for *S. marianum* invasion. Many environmental groups have also called for eliminating invasive species, such as this particular weed. Pakistan's National Institute of Health in Islamabad has granted the construction of a ten-hectare traditional medicine park and botanical garden to lessen Pakistan's dependence on imported medicinal plants, including *S. marianum*, and generate cash [23].

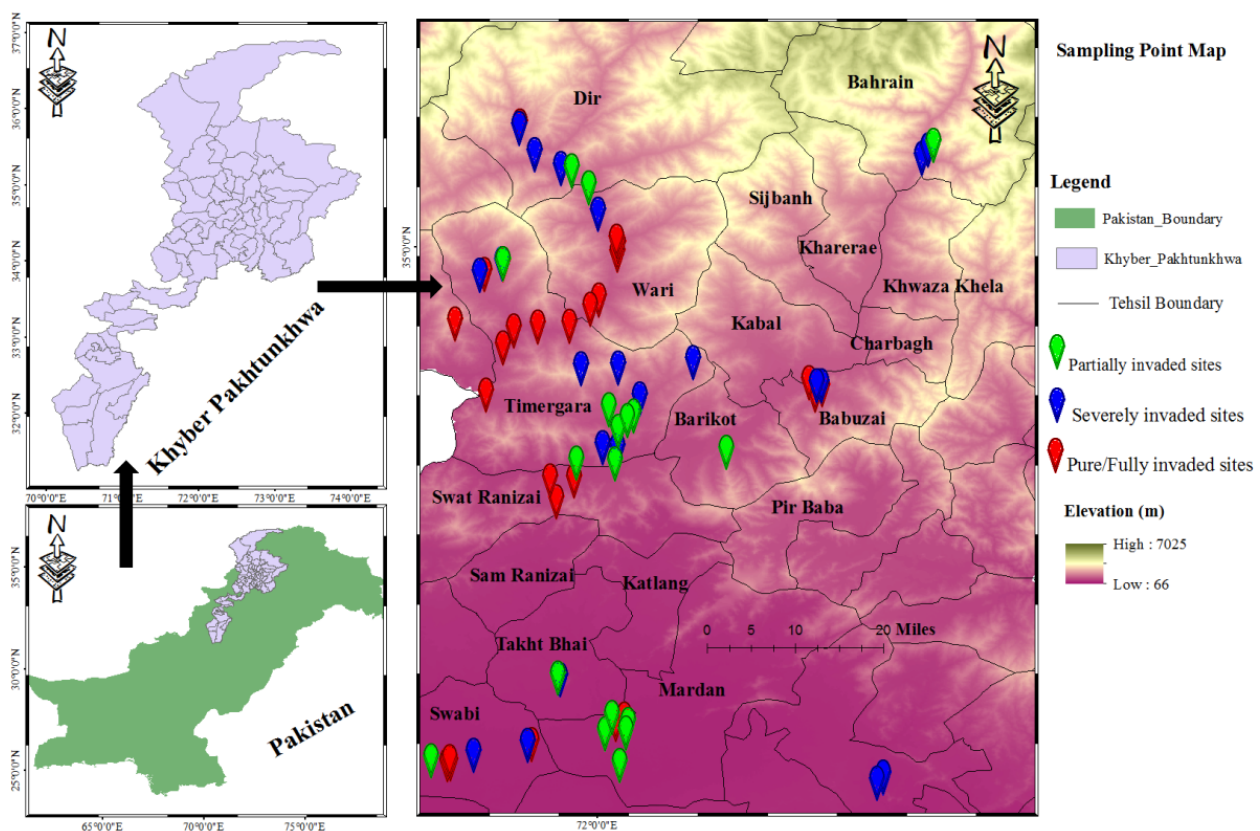
Invasive species *S. marianum* is likely to alter the native plant community's richness, diversity, and composition due to its presence. Therefore, it was selected as a model plant for the current study. Thus, the species' spatial distribution pattern and ecological impacts on local diversity in Khyber Pakhtunkhwa, Pakistan were assessed to evaluate its invasive behavior. The environmental conditions and soil factors that affect plants' potential to spread were also evaluated to better understand the conditions which sustain these communities. We hypothesized that *S. marianum* would perform better than expected at higher elevations and steeper terrain. These assumptions were evaluated using field data, including comparing vegetation composition with decreasing degrees of *S. marianum* invasion intensity in terms of the Importance Value Index (IVI) and Species Diversity Indexes (SDI).

## 2. Materials and Methods

### 2.1. Study Area and Sampling Sites

Khyber Pakhtunkhwa (KP), one of Pakistan's five administrative provinces, is situated in the country's northwestern part. The Himalayan, Hindukush, and Karakorum mountain ranges form the province's northern and eastern boundaries. The Hindukush mountain range stretches from the lowlands (327 m above sea level in Peshawar) to the highlands (7708 m above sea level at Tirch Mir) [24]. The sample sites range from 360 m to 1200 m above sea level and are located between 34.59 and 34.85 N° latitudes (Figure 1). The

province is divided into four distinct agro-ecological zones based on the area's geography and climate. Undulating plains and mountains surround the province, creating a climatic gradient that influences the south to the north and northwest. The climate in this area is mild all year round. There is a notable difference in temperature between the north and the south of the highlands [25]. June is the hottest month, with mean maximum and minimum temperatures of  $35.01 \pm 0.96$  degrees Celsius and  $18.20 \pm 0.58$  degrees Celsius. Winters are harsher since the temperature seldom rises above freezing point, and January is the coldest month with average maximum and minimum temperatures of  $14.45 \pm 2.10$  °C and  $0.83 \pm 0.82$  °C, respectively [26]. In terms of yearly precipitation, the range is 379–743 mm with a relative humidity of  $55.32 \pm 1.98$  percent to  $78.41 \pm 2.92$  percent [25]. Because the region's economic, social, hydrological, and agricultural activities heavily depend on the climate, its evaluation is necessary in understanding plant communities [27].



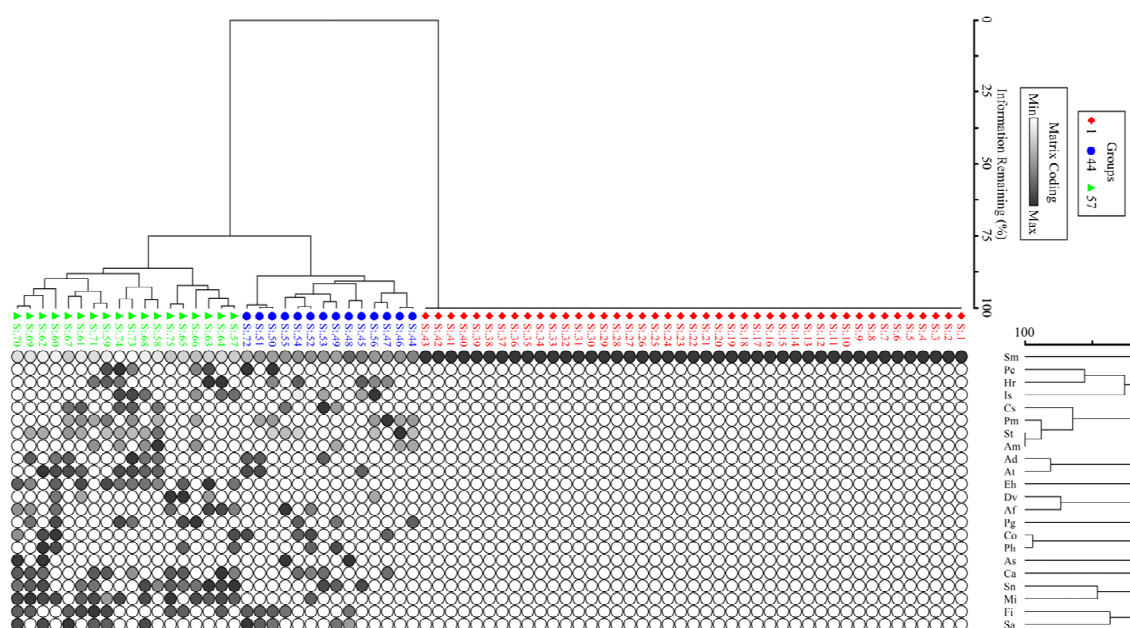
**Figure 1.** Study area map showing the different invaded sites dominated by *Silybum marianum*.

Fieldwork was conducted during and just after this period, and data was collected from April to July 2021 because most plants sprout, leaf out, or bear fruit during the rainy season. The ecological implications of *S. marianum* were quantified in three distinct habitats (Figure 1).

The three types of habitats (Table 1) in the plains and hills of KP, Pakistan, with long-term populations of *S. marianum* include (a) relatively plain/flat areas, sites at low elevation in which *S. marianum* is favored by the semi-arid environmental conditions where pure communities exist (Pure sites, Group I), (b) an intermediate elevation zone, sites of relatively humid and sub-tropical condition (Severely invaded sites, Group II), and (c) sites relatively safe from human activities, having higher elevation (Partially invaded sites, Group III) as separated by clusters presented in Figure 2. The sites were selected randomly, and vegetation sampling was performed following the method in [28]. Selection and sampling of habitats in such a manner provide a reliable picture of invasive success and effect in the highland regions studied.

**Table 1.** Site conditions of *Silybum marianum* sampling areas distributed in Khyber Pakhtunkhwa, Pakistan.

Group-I	Group-II	Group-III
<ul style="list-style-type: none"> <li>Pure/fully invaded sites</li> <li>100% importance value index of <i>S. marianum</i></li> <li>Low elevation, flat plain</li> </ul>	<ul style="list-style-type: none"> <li>Severely invaded sites</li> <li>&lt;60% importance value index of <i>S. marianum</i></li> <li>Intermediate elevation, subtropical humid conditions</li> </ul>	<ul style="list-style-type: none"> <li>Partially invaded sites</li> <li>&lt;30% importance value index of <i>S. marianum</i></li> <li>Higher elevation, humid temperate regions</li> </ul>

**Figure 2.** Cluster dendrogram of the *Silybum marianum* communities for classification and separation.

## 2.2. Vegetation Sampling

A total of 75 sites, each having 10 plots of  $5 \times 5$  m areas ( $25 \text{ m}^2$ ), were sampled, where phytosociological attributes such as frequency, density, and cover were measured and converted into their respective relative attributes for calculating the IVI of each species to assess the potential effects of *S. marianum* by following [28,29].

$$\text{IVI} = F_3 + D_3 + C_3/3 \quad (1)$$

$F_3$ ,  $D_3$ , and  $C_3$  represent the species' relative frequency, density, and cover.

Plant species were identified using Flora of Pakistan and Kew Botanical Garden's Plants of the World website (<http://www.plantsoftheworldonline.org> (accessed on 14 January 2022)) [30]. For accurate identification of some species, specimens were taken to the Herbarium of the University of Malakand. The sampling approach examined species composition and compared species richness and diversity. Species diversity indices were estimated using the following equations by following [31].

$$H' = \sum_{i=1}^S p_i \ln p_i \quad (2)$$

$$E = \frac{H'}{\ln S} \quad (3)$$

$$1/D = 1/\sum (p_i^2) \quad (4)$$

$$S = St/a \quad (5)$$



where  $H'$  is Shannon–Wiener diversity index;  $E$  is Evenness index;  $1/D$  is Simpson's index;  $S$  is species richness;  $p_i$  is Species proportion;  $\ln$  is Natural logarithm;  $St$  is Number of individuals in total plots;  $a$  is Total plot numbers.

### 2.3. Environmental and Soil Variables

Samples from three sides of each plot were averaged to represent environmental factors accurately. The grinding process removed plant debris and tiny stones from each sample, allowing it to air-dry. After passing through a 2 mm screen, each sample's physiochemical characteristics and nutrients were determined. Soil texture parameters were calculated using the Bouyoucos hydrometer technique, and pH was immediately measured using a pH meter (Model CON.3173) in the field after a soil suspension (1:5) had been prepared [32]. An Atomic Absorption Spectrophotometer [33] measured potassium in an unbuffered solution of  $NH_4OAc$  of IM concentration to determine organic matter (VARIAN model-AA2407, VARIAN, Palo Alto, CA, USA). An auto-analyzer was used to measure nitrogen, and an  $NaHCO_3$  concentration of 0.5 M was used to estimate phosphorus using the calorimetric method [34,35]. A conductometer was used to measure electrical conductivity (Model CON 5). Other variables considered were altitude in meters above sea level (asl), soil pH in water, slope angle in degrees, and depth in centimeters of the soil in the test plots. The environmental characteristics are represented by an average value derived from samples obtained from three different locations on each plot.

### 2.4. Data Analyses

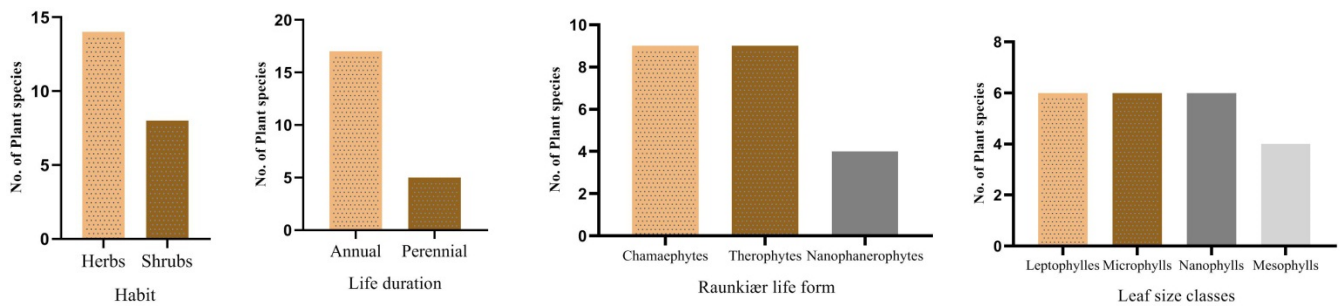
Ward's agglomerative cluster analysis was employed to classify vegetation stands since species distribution fluctuates along an elevation and IVI gradient; this approach was favored over others and used PC-ord version 6 by measuring Euclidean distance, using Ward's linkage method [36]. Using PC-ord version 6, Canonical correspondence analysis (CCA) was used to assess the influence of environmental and soil variables on vegetation groups. First, DCA-ordination was used to determine whether unimodal [37,38] or linear [39] response curves should be utilized in ordination analysis. CCA and redundancy analysis (RDA) was used to determine the species–environment correlation as the gradient length exceeded 4.1 on DCA-axis 1. There were 30 percent higher variances in CCA than in RDA ordination, and the stand distribution was more uniform in CCA-biplots than in RDA, and therefore preferred in analysis. SPSS version 22 was utilized for statistical analysis, and Excel 2010 was used for tabulation and visual display. Variables were assessed at  $p < 0.05$ , and the HSD test was also utilized to analyze the variance in the groups after the analysis of variance (ANOVA).

## 3. Results

### 3.1. Phytosociological/Vegetation Traits

In the 750 plots dominated or invaded by *S. marianum*, 22 plant species from 12 families were identified. Asteraceae, Poaceae, Amaranthaceae, and Solanaceae were the most dominant families. The species discovered were mostly annual plants belonging to the Phanerophytes and Chamaephytes Raunkiaer life-form categories (Figure 3).

The IVI of the *S. marianum* decreased progressively with elevation, having no co-dominant species in pure communities at low elevation. In severely invaded communities (Group II, IVI > 60%), there were three co-dominant species, i.e., *Phalaris minor* Retz., having an IVI of  $4.47 \pm 1.55$ , *Stylosanthes humilis* Kunth, having an IVI of  $3.72 \pm 1.56$  and *Fumaria indica* Hausskn., having an IVI of  $2.66 \pm 0.99$ . In the partially invaded communities (Group III, IVI > 30%), the three co-dominant species were *Melilotus indicus* (L.) All., *Solanum nigrum* L., and *Euphorbia helioscopia* L., having IVIs of  $6.75 \pm 0.90$ ,  $5.81 \pm 0.90$ , and  $5.12 \pm 0.91$ , respectively. The species importance value index varies significantly with community type variation (Groups I–III) (Table 2).



**Figure 3.** Floristic characteristics of the vegetation found in association with *Silybum marianum* in communities (Details available in Supplementary Table S1).

**Table 2.** Importance value index of *Silybum marianum* and associated species found in the three groups separated by cluster analysis.

Species	Ac	Group I	Group II	Group III	F	p-Value
		Mean ± SE	Mean ± SE	Mean ± SE		
<i>Silybum marianum</i> (L.) Gaernt	Sm	100 ± 0 a	62.44 ± 1.91b	30.44 ± 1.75 c	1451.3	6.61 × 10 <sup>−59</sup>
<i>Amaranthus viridis</i> L.	Am	0 ± 0 a	1.03 ± 0.70 b	3.1 ± 1.28 c	7.11	0.001514
<i>Artemisia scoparia</i> Waldst. & Kit.	As	0 ± 0 a	1.58 ± 0.84 b	3.35 ± 0.91 c	13.63	9.50 × 10 <sup>−6</sup>
<i>Asphodelus tenuifolius</i> Cav.	Ad	0 ± 0 a	1.71 ± 0.91 b	2.62 ± 0.91 c	8.59	0.0004
<i>Avena fatua</i> L.	Af	0 ± 0 a	1.27 ± 0.88 b	3.07 ± 0.96 c	10.16	0.00012
<i>Avena sativa</i> L.	As	0 ± 0 a	1.03 ± 0.70 b	0.77 ± 0.53 c	3.07	0.052573
<i>Cannabis sativa</i> L.	Cs	0 ± 0 a	1.64 ± 0.90 b	2.22 ± 0.87 c	6.94	0.0017
<i>Carthamus oxyacantha</i> M.Bieb.	Co	0 ± 0 a	2.18 ± 0.96 b	1.67 ± 0.77 c	6.99	0.0016
<i>Chenopodium murale</i> L.	Cm	0 ± 0 a	2.11 ± 0.92 b	5.06 ± 1.08 c	21.18	5.84 × 10 <sup>−8</sup>
<i>Cortaderia selloana</i> (Schult. & Schult.f.) Asch. & Graebn.	Pg	0 ± 0 a	1.64 ± 0.87 b	2.85 ± 0.99 c	9.04	0.000315
<i>Dodonaea viscosa</i> Jacq.	Dv	0 ± 0 a	0.51 ± 0.51 b	3.26 ± 1.37 c	7.91	0.0007
<i>Euphorbia helioscopia</i> L.	Eh	0 ± 0 a	0 ± 0 a	5.12 ± 0.91 b	50.89	1.67 × 10 <sup>−14</sup>
<i>Fumaria indica</i> Hausskn.	Fi	0 ± 0 a	2.66 ± 0.99 b	4.3 ± 1.04 c	17.89	4.91 × 10 <sup>−7</sup>
<i>Hypochaeris radicata</i> L.	Hr	0 ± 0 a	2.38 ± 0.91 b	2.36 ± 0.94 c	8.78	0.000387
<i>Lathyrus sativus</i> L.	Ls	0 ± 0 a	1.61 ± 0.88 b	2.94 ± 1.01 c	10.77	8.08 × 10 <sup>−5</sup>
<i>Melilotus indicus</i> (L.) All.	Mi	0 ± 0 a	0.57 ± 0.57 b	6.75 ± 0.90 c	68.9	1.90 × 10 <sup>−17</sup>
<i>Parthenium hysterophorus</i> L.	Ph	0 ± 0 a	1.06 ± 0.73 b	1.69 ± 0.77 c	5.123	0.00831
<i>Phalaris caroliniana</i> Walter	Pc	0 ± 0 a	1.13 ± 0.77 b	1.85 ± 0.73 c	6.24	0.0031
<i>Phalaris minor</i> Retz.	Pm	0 ± 0 a	4.47 ± 1.55 b	3.41 ± 1.07 c	12.91	1.61 × 10 <sup>−5</sup>
<i>Solanum nigrum</i> L.	Sn	0 ± 0 a	1.89 ± 1.01 b	5.81 ± 0.90 c	35.39	1.97 × 10 <sup>−11</sup>
<i>Spergula arvensis</i> L.	Sa	0 ± 0 a	2.69 ± 1.04 b	2.97 ± 1.02 c	10.38	0.000109
<i>Stylosanthes humilis</i> Kunth	Sh	0 ± 0 a	3.72 ± 1.56 b	4.65 ± 1.19 c	13.78	8.52 × 10 <sup>−6</sup>

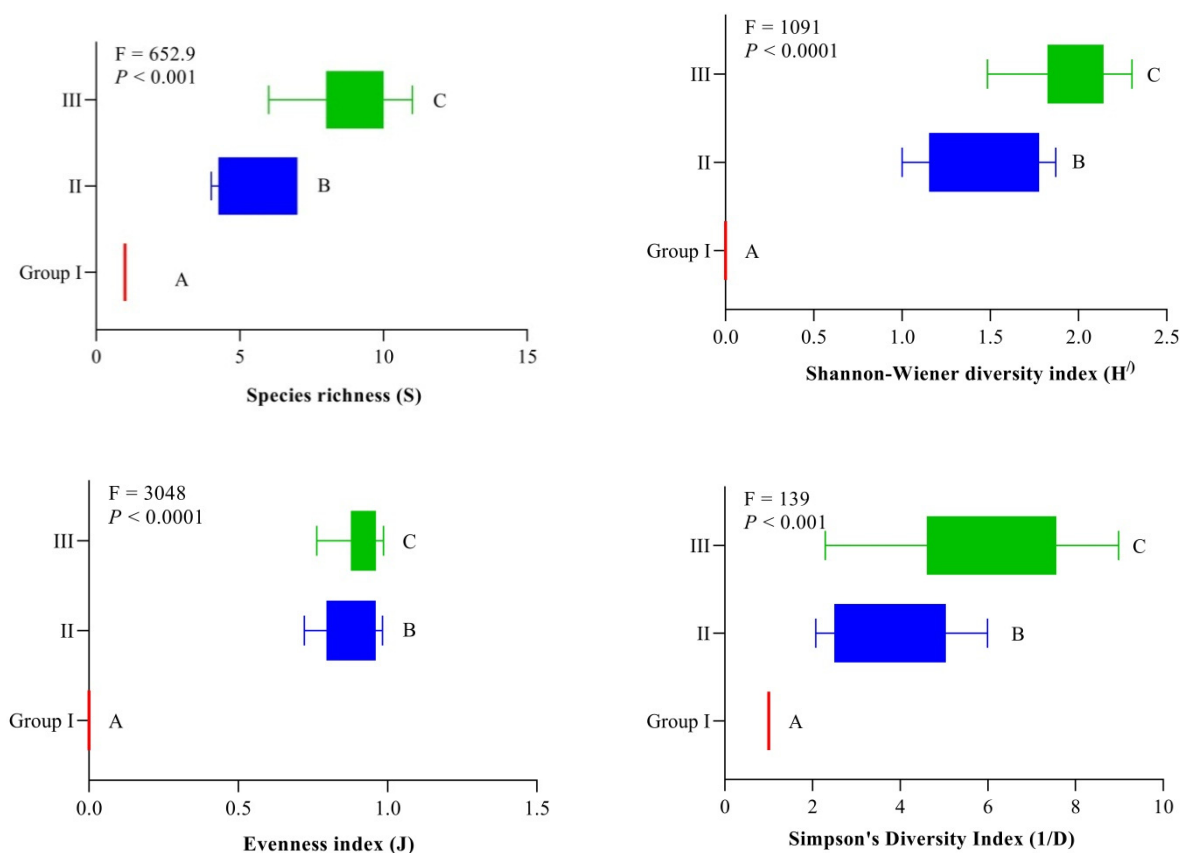
Note: Ac, Species acronyms; Mean ± SE, Mean ± Standard error; Different letters indicate significant differences.

The species richness ( $p < 0.05$ ), Shannon diversity index ( $p < 0.05$ ), Evenness index ( $p < 0.05$ ), Margelof index ( $p < 0.05$ ), and Simpson index ( $p < 0.05$ ) differ significantly between and among the purely, severely, and partially invaded sites. Furthermore, the diversity indices trends are inversely related to the *S. marianum* importance value index (Figure 4).

### 3.2. Environmental Variables

The environmental variables show that the sampling stands of *S. marianum* communities of Group I are situated at low altitude ( $340.15 \pm 4.84$  m ASL), are purely invaded, with low organic matter, nitrogen, lime, and potassium, and have a higher concentration of phosphorus. Group II, with an elevation of  $859.38 \pm 13.75$  m ASL, has the highest organic matter, nitrogen, and phosphorus concentrations, whereas the potassium concentration was intermediate (Table 3). The partially invaded sites are found at higher elevations ( $1548.64 \pm 35.37$  m asl), having intermediate quantities of organic matter, nitrogen, and phosphorus, whereas they have higher quantities of potassium and lime. Among the physical parameters, % of silt particles is marginally higher than sand ( $31.94 \pm 1.4$ %) and clay ( $31.58 \pm 1.2$ %) in Group I, which shows that the soil is loamy in texture. Among the soil of other groups, the % mean values of sand particles are higher than silt and clay

particles. The same is true for soil texture in Groups II and III. The pH of the soil was found to be a little acidic in Groups II and II ( $5.45 \pm 0.05$  and  $5.73 \pm 0.04$ ) and almost neutral in Group III ( $6.75 \pm 0.10$ ).



**Figure 4.** Diversity indices of the communities dominated by *Silybum marianum* with progressive decrease of importance value index. Note: Different letters indicate significant variation at  $p < 0.05$ .

**Table 3.** Environmental and soil variables associated with *Silybum marianum* communities.

Factors	Group 1	Group II	Group III	F-Value	p-Value
Elevation	340.15 $\pm$ 4.84 a	859.38 $\pm$ 13.75 b	1548.64 $\pm$ 35.37 c	50.81	0.000
Latitude (°)	34.76 $\pm$ 0.11	34.67 $\pm$ 0.1	34.66 $\pm$ 0.86	0.365	0.69
Longitude (°)	71.86 $\pm$ 0.81	72.09 $\pm$ 0.06	71.94 $\pm$ 0.05	0.365	0.69
Aspect degree	93.79 $\pm$ 6.3	118.15 $\pm$ 13	111.6 $\pm$ 10.1	2.13	0.12
Clay (%)	31.58 $\pm$ 1.2	31.96 $\pm$ 2.9	34.55 $\pm$ 2.2	0.784	0.46
Silt %	36.59 $\pm$ 1.4	36.25 $\pm$ 2.6	32.76 $\pm$ 2.3	1.07	0.35
Sand (%)	31.94 $\pm$ 1.4	31.77 $\pm$ 2.5	32.68 $\pm$ 1.8	14.03	$7.11 \times 10^{-6}$
pH (1:5)	6.75 $\pm$ 0.10	5.45 $\pm$ 0.05	5.73 $\pm$ 0.04	45.64	$1.57 \times 10^{-13}$
Organic matter (%)	0.55 $\pm$ 0.04	0.61 $\pm$ 0.07	0.57 $\pm$ 0.05	0.793	3.124
Lime %	11.21 $\pm$ 0.5	11.63 $\pm$ 1.9	12.1 $\pm$ 0.08	0.419	0.66
Nitrogen %	2.114 $\pm$ 1.2	4.77 $\pm$ 4.3	3.39 $\pm$ 2.2	0.382	0.68
Conductivity ( $\mu$ S/cm)	37.74 $\pm$ 1.7	42.07 $\pm$ 2.7	57 $\pm$ 18.49	1.43	0.24
Phosphorus (mg/kg)	6.726 $\pm$ 6.3	6.6 $\pm$ 0.72	6.34 $\pm$ 0.49	0.25	0.78
Potassium (mg/kg)	137.7 $\pm$ 4.9	145.84 $\pm$ 13	157.2 $\pm$ 8.3	1.92	0.15

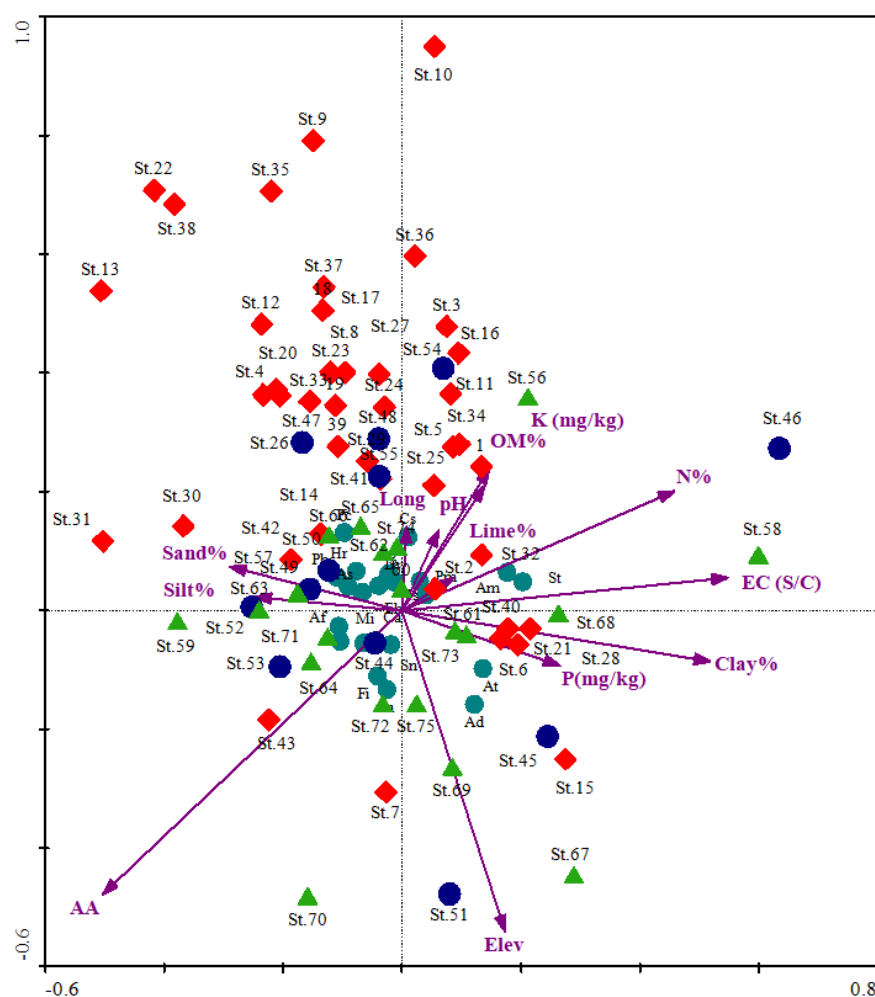
Different letters represent significance at  $p < 0.05$ .

The species–environment correlation was tested using Canonical correspondence analysis, which revealed the data loaded on axis 1, having an Eigenvalue of 0.34 with a % variance of 22.8, showing 88% of the Pearson's correlation. The cumulative variance explained by all the three axes was 29.9%, in which the axis 2 and 3 contributions were 4.4 and 2.8 percent, respectively (Table 4).

**Table 4.** Axis summary and commutative variance of the variables affecting *Silybum marianum* communities.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.384	0.075	0.047
Data variance			
Explained variance in %	22.8	4.4	2.8
Explained cumulative %	22.8	27.2	29.9
Pearson Correlation	0.888	0.65	0.676
Kendall (Rank) Correlation	0.684	0.376	0.363

The ordination biplot revealed a clear-cut deflection and separation of purely invaded sites from severely and partially invaded sites. The biplot revealed that the communities are affected by soil textural (sand, silt, and clay), nutrient (lime %, potassium and phosphorus in mg/kg), and environmental (aspect degree and elevation) variables (Figure 5).

**Figure 5.** Canonical correspondence analysis biplot showing the relation of vegetation and related environmental and soil variables.

The correlation and biplot scores revealed the same loading of axis 1 with higher correlation scores for the environmental variables. The soil textural parameters were found to have a high correlation, i.e.,  $r = 0.91$ ,  $0.77$ , and  $-0.52$  for clay, silt, and sand percentages, respectively, on axis 1. In nutrient organic matter, lime, nitrogen, potassium, and phosphorus were found to have a significant negative correlation on axis 1, whereas nitrogen and organic matter have a significant positive correlation on axis 2 (Table 5).



**Table 5.** Correlation and biplot scores of the environmental and soil variables operating on the *Silybum marianum* communities.

	Variable	Correlation			Biplot Scores		
		Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 3
1	Latitude (°)	0.104	0.015	0.023	0.081	0.014	0.023
2	Longitude (°)	0.104	0.015	0.023	0.081	0.014	0.023
3	Elev.	0.638	−0.178	0.005	0.001	0.001	0.012
3	AA (°)	−0.237	−0.002	0.316	−0.186	−0.002	0.309
4	CLY (%)	0.912	−0.091	0.075	0.716	−0.088	0.073
5	SLT %	0.777	−0.086	−0.057	0.61	−0.083	−0.055
6	SND (%)	−0.528	−0.082	0.202	−0.415	−0.078	0.198
7	pH (1:5)	0.176	0.15	−0.125	0.138	0.144	−0.122
8	Organic matter (%)	−0.217	0.769	0.12	−0.17	0.74	0.118
9	Lime %	0.882	−0.02	0.068	0.692	−0.02	0.066
10	Nitrogen %	−0.41	0.646	0.098	−0.322	0.622	0.095
11	Conductivity (µs/cm)	−0.818	0.251	−0.028	−0.642	0.241	−0.027
12	Phosphorus (mg/kg)	−0.95	0.016	−0.075	−0.745	0.015	−0.074
13	Potassium (mg/kg)	−0.918	0.109	0.073	−0.72	0.105	0.071

#### 4. Discussion

Plant communities were significantly homogenized by *S. marianum*'s presence, and its invasion significantly influenced species richness and diversity indices. As a result, the expansion and abundance of *S. marianum* reduced the landscape-level heterogeneity or spatial variety of the native plant groups. Invasive species have been demonstrated in alternative plant ecosystems, consistent with this study's findings [40–43]. *Solidago canadensis* invasions, for example, have resulted in community homogeneity across multiple habitats and landscapes that were formerly dominated by distinct native species populations. The patterns of communities invaded by *S. canadensis* differed much from those in control locations and are consistent with the idea that invasive species tend to homogenize communities, which is found to be in compliance with our results.

The homogenization of communities by *S. marianum* is supported by communities' physiognomic characteristics. Plant habits and biological life forms play a key role in promoting biotic homogeneity and plant community disruptions. Among the three communities studied, we observed that 64 percent of herbaceous plants, mostly of an annual character (77.7%), supported the results of [44,45]. In comparison with perennial plants, annual and biennial herbaceous species were shown to have a greater impact on promoting the homogeneity of plant communities. However, this is not the consensus among researchers, as others have found plant homogeneity in perennials, e.g., [46,47]. As an annual herb, *S. marianum* produces enormous numbers of viable seeds, quickly spreading and propagating across the area, disrupting the structure of the local plant communities and other trophic levels. In addition, *S. marianum* may be found in many different environments, including farmland, reducing crop yields. It is inedible to cattle and substitutes valuable fodder plants such as *Rumex hastatus* and *Cenchrus ciliaris*. The productivity of cereal crops, including wheat, barley, and maize, and pasture quality, may be adversely affected by the invasion of *S. marianum*, as reported by [22,48,49].

*S. marianum*'s propensity to produce homogeneous stands is a hallmark of this species, and it seems to be motivating the invasion of native species [50]. Invasions have previously been shown to impact community species richness [51]. Changes to the makeup of the invaded communities may lead to a rise in native, fast-growing species. *Carthamus oxyacantha*, a fast-growing, semi-succulent herbaceous plant, was more common alongside *S. marianum*. We hypothesize that *S. marianum* alters anthropogenic and soil-variable patterns, affecting native diversity. For this reason, the presence of *S. marianum* has a discernible effect on the variety and richness of native species. *S. marianum* probably provides habitat for species vulnerable to herbivory and competes for space with browsing-tolerant species. According

to these findings, *S. marianum* may have a greater influence on native plant variety and richness than previously assumed. In Kenya, [52] reported on a similar circumstance, in which the natural vegetation of Nairobi National Park was surveyed to compare invaded and un-invaded locations. In contrast to our findings, these researchers observed that invasive-species-infested ecosystems had a considerably larger variety of native species.

We found that *S. marianum*'s invasion of the lowlands fully homogenized the plant community and expanded to the highlands. The invasion seems to impact species richness and variety, but it also has the unintended effect of homogenizing the ecosystem. This issue will most likely be worsened in the future by climate change and the local community's lack of understanding of the implications of *S. marianum*'s invasion, as successful recruitment and densification of existing *S. marianum* stands continue across the elevation, supporting the findings of [53]. Improving the plant's ability to withstand drought by cultivating it for local purposes (mostly medicinal and phytochemicals) might lead to the additional spread of this invasive species, as revealed by [54], and interfere with the native vegetation's spatial diversity and ecosystem processes. In the long run, it is expected to be the most prevalent species in the area, with an increasing influence on native flora. Raising local awareness of the problem and avoiding the future spread of the species to other natural environments is now the true task to be faced here.

*S. marianum*'s ability to thrive relies on its distinct biological properties and the environmental conditions it invades. Resources may fluctuate in abundance, making plant populations vulnerable to invasive species [55]. According to this idea, water availability in semi-arid areas is an example, since temporal oscillations produce a periodic shortage of resources, replenishing following rains. *S. marianum*, a drought-resistant invasive species, may thrive under a water-pulse regime that leaves other populations susceptible. Temperature and moisture changes in the research region are likely to boost the competitive ability of *S. marianum*, hence its invasiveness, which derives from even drier circumstances [56]. Controlled competition trials of *S. marianum* and native plants are required to properly forecast the future invasive potential of *S. marianum*.

The richness and composition of native plant communities are jeopardized and fragile, making the native endangered species particularly susceptible to extinction [57] due to invasive species. Their ability to affect local soils' physical and chemical qualities is a significant aspect in disturbing the communities that mostly leads to homogenization [58]. Our findings support these generalizations, which show that *S. marianum* has a major influence on plant and soil ecosystems alike. With the rising IVI of *S. marianum*, the Shannon–Wiener diversity index, Margalef's richness index, and evenness index decline; however, Simpson's dominance index rises with the invasion gradient. Many other invaded parts of the globe have yet to experience the harmful ecological effects of *S. marianum* [59–62]. Physiochemical qualities differed significantly across locations that had been completely, substantially, or partly invaded. The soil's build-up of secondary metabolites (especially phenolic acids) is reflected in increased acidity, electrical conductivity, and phosphorus content in strongly invaded locations [63]. *S. marianum* IVI may lead to increased decomposition residues and quicker decomposition rates in the soil, as reported by [64–66]. It has been found that decomposing plant residues alter soil properties and the biotic/abiotic composition of the soil [67–69] for *Lantana camara* L, *Robinia pseudoacacia*, *Acacia* spp., and *Lonicera maackii* (Rupr.) Maxim, as reported in [67,69]. Consequently, additional research is needed to confirm that *S. marianum* invasion has changed the characteristics of soils with high organic carbon content, which is consistent with the findings of this study.

## 5. Conclusions

1. The findings show that *S. marianum* is found in low-elevation pure communities, and progressive spreading to higher elevations significantly influences local diversity and homogenizes the region.

2. There was a clear correlation between the *S. marianum* importance value index and the diversity indices, with the latter decreasing as the former increased, and this is a possible hazard to the biodiversity of the native region.
3. Communities' responses were found to be complemented by changes in environmental variables. The results revealed that the nutrient concentrations in the severely invaded sites were more significant than those in the pure and partially invaded sites.
4. The management and control of this species are thus necessary for conserving and maintaining natural vegetation.
5. These findings open up many possibilities for further research. It can forecast not just the behavior of *S. marianum* but also the behavior of other invasive plant species with phylogenetic or morphological similarities with *S. marianum*.
6. This research will be extremely important in increasing our understanding of the distribution, development, and spread of alien invasive species along various climatic gradients in observed and predicted fast climate change.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/agriculture12050687/s1>, Table S1: Floristic list and characteristics of plants found in association with *S. marianum* in severely and partially invaded sites.

**Author Contributions:** N.K. supervised the research work. R.U. collected the data and wrote the initial draft of the manuscript. K.A. provided meaningful help in data visualization and language editing. M.E.H.K. provided valuable support in methodology and results organization. D.A.J. provided substantial guidelines in discussion, organization, and manuscript drafting. All authors have read and agreed to the published version of the manuscript.

**Funding:** The publication fee is partially funded by Qatar National Library.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** All the data presented in the manuscript is available.

**Acknowledgments:** We greatly acknowledge the efforts of Wajid Mehmood in providing key support in data collection and visit during the research work. We also acknowledge arid agriculture institute Swat for soil analysis and support.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Latombe, G.; Roura-Pascual, N.; Hui, C. Similar compositional turnover but distinct insular environmental and geographical drivers of native and exotic ants in two oceans. *J. Biogeogr.* **2019**, *46*, 2299–2310. [\[CrossRef\]](#)
2. Zeng, H.; Jia, G.; Epstein, H. Recent changes in phenology over the northern high latitudes detected from multi-satellite data. *Environ. Res. Lett.* **2011**, *6*, 045508. [\[CrossRef\]](#)
3. Moradi, P.; Aghajanloo, F.; Moosavi, A.; Minfared, H.H.; Khalafi, J.; Taghiloo, M.; Mastinu, A. Anthropic Effects on the Biodiversity of the Habitats of *Ferula gummosa*. *Sustainability* **2021**, *13*, 7874. [\[CrossRef\]](#)
4. Stohlgren, T.; Rejmánek, M. No universal scale-dependent impacts of invasive species on native plant species richness. *Biol. Lett.* **2014**, *10*, 2013093. [\[CrossRef\]](#) [\[PubMed\]](#)
5. Stohlgren, T.J.; Barnett, D.T.; Jarnevich, C.S.; Flather, C.; Kartesz, J. The myth of plant species saturation. *Ecol. Lett.* **2008**, *11*, 313–322. [\[CrossRef\]](#) [\[PubMed\]](#)
6. Pauchard, A.; Shea, K. Integrating the study of non-native plant invasions across spatial scales. *Biol. Invasions* **2006**, *8*, 399–413. [\[CrossRef\]](#)
7. Powell, K.I.; Chase, J.M.; Knight, T.M. A synthesis of plant invasion effects on biodiversity across spatial scales. *Am. J. Bot.* **2011**, *98*, 539–548. [\[CrossRef\]](#)
8. Price, E.P.F.; Spyreas, G.; Matthews, J.W. Biotic homogenization of regional wetland plant communities within short time-scales in the presence of an aggressive invader. *J. Ecol.* **2018**, *106*, 1180–1190. [\[CrossRef\]](#)
9. Chytrý, M.; Jarošík, V.; Pyšek, P.; Hájek, O.; Knollová, I.; Tichý, L.; Danihelka, J. Separating habitat invasibility by alien plants from the actual level of invasion. *Ecology* **2008**, *89*, 1541–1553. [\[CrossRef\]](#)
10. Smart, S.M.; Thompson, K.; Marrs, R.H.; Le Duc, M.G.; Maskell, L.C.; Firbank, L.G. Biotic homogenization and changes in species diversity across human-modified ecosystems. *Proc. R. Soc. B Biol. Sci.* **2006**, *273*, 2659–2665. [\[CrossRef\]](#)

11. Morri, C.; Montefalcone, M.; Gatti, G.; Vassallo, P.; Paoli, C.; Bianchi, C.N. An Alien Invader is the cause of homogenization in the recipient ecosystem: A simulation-like approach. *Diversity* **2019**, *11*, 146. [\[CrossRef\]](#)
12. Wilson, J.R.; Richardson, D.M.; Rouget, M.; Procheş, Ş.; Amis, M.A.; Henderson, L.; Thuiller, W. Residence time and potential range: Crucial considerations in modelling plant invasions. *Divers. Distrib.* **2007**, *13*, 11–22. [\[CrossRef\]](#)
13. Obiri, J.F. Invasive plant species and their disaster-effects in dry tropical forests and rangelands of Kenya and Tanzania. *J. Disaster Risk Stud. Jambá* **2011**, *3*, 417–428. [\[CrossRef\]](#)
14. Hamouda, M. Molecular analysis of genetic diversity in population of *Silybum marianum* (L.) Gaertn in Egypt. *J. Genet. Eng. Biotechnol.* **2019**, *17*, 12. [\[CrossRef\]](#) [\[PubMed\]](#)
15. Groves, R.H.; Kaye, P.E. Germination and phenology of seven introduced thistle species in Southern Australia. *Aust. J. Bot.* **1989**, *37*, 351–359. [\[CrossRef\]](#)
16. Mohammadi, S.A.; Shokrpour, M.; Moghaddam, M.; Javanshir, A. AFLP-based molecular characterization and population structure analysis of *Silybum marianum* L. *Plant Genet. Resour.* **2011**, *9*, 445–453. [\[CrossRef\]](#)
17. Omidbaigi, R.; Nobakht, A. Nitrogen fertilizer affecting growth, seed yield and active substances of milk thistle (*Silybum marianum*). *Pak. J. Biol. Sci.* **2001**, *4*, 1345–1349.
18. Rafizadeh, A.; Koohi-Dehkordi, M.; Sorkheh, K. Molecular insights of genetic variation in milk thistle (*Silybum marianum* [L.] Gaertn.) populations collected from southwest Iran. *Mol. Biol. Rep.* **2018**, *45*, 601–609. [\[CrossRef\]](#)
19. Holm, L.G.; Doll, J.; Holm, E.; Pancho, J.; Herberger, J. World Weeds. In *Natural Histories and Distribution*; Wiley: New York, NY, USA, 1997.
20. Berner, D.K.; Paxson, L.K.; Bruckart, W.L.; Luster, D.G.; McMahon, M.B.; Michael, J.L. First report of *Silybum marianum* as a host of *Puccinia punctiformis*. *Plant Distrib.* **2002**, *86*, 1271. [\[CrossRef\]](#)
21. Gabay, R.; Plitmann, U.; Danin, A. Factors affecting the dominance of *Silybum marianum* L. (Asteraceae) in its specific habitats. *Flora* **1994**, *189*, 201–206. [\[CrossRef\]](#)
22. Marwat, K.B.; Hussain, Z.; Gul, B.; Saeed, M.; Din, S. Survey on weed problems in wheat crop in district Mardan. *Pak. J. Weed Sci. Res.* **2006**, *12*, 353–358.
23. Saeed, A. Milk Thistle Seeds. Ray's Herbs Trading Company, Karachi, Pakistan. 2008. Available online: <http://itrademarket.com/rays> (accessed on 22 August 2020).
24. Rahman, A.; Dawood, M. Spatio-statistical analysis of temperature fluctuation using Mann–Kendall and Sen's slope approach. *Clim. Dyn.* **2016**, *48*, 783–797. [\[CrossRef\]](#)
25. Ali, A.; Khan, T.A.; Ahmad, A. Analysis of Climate Data of Khyber Pakhtunkhwa, Pakistan. *Int. Res. J. Eng. Technol.* **2018**, *5*, 4266–4283.
26. Shah, A.A.; Ye, J.; Abid, M.; Ullah, R. Determinants of flood risk mitigation strategies at household level: A case of Khyber Pakhtunkhwa (KP) province, Pakistan. *Nat. Hazards* **2017**, *88*, 415–430. [\[CrossRef\]](#)
27. Deo, R.C.; Şahin, M. Application of the Artificial Neural Network model for prediction of monthly Standardized Precipitation and Evapotranspiration Index using hydrometeorological parameters and climate indices in eastern Australia. *Atmos. Res.* **2015**, *161*, 65–81. [\[CrossRef\]](#)
28. Ali, F.; Khan, N.; Ahmad, A.; Khan, A.A. Structure and biomass carbon of *Olea ferruginea* forests in the foot hills of Malakand division, Hindukush Range Mountains of Pakistan. *Acta Ecol. Sin.* **2019**, *39*, 261–266. [\[CrossRef\]](#)
29. Aghajanolou, F.; Mirdavoudi, H.; Shojaee, M.; Mac Sweeney, E.; Mastinu, A.; Moradi, P. Rangeland management and ecological adaptation analysis model for *Astragalus curvirostris* Boiss. *Horticulturae* **2021**, *7*, 67. [\[CrossRef\]](#)
30. Ali, S.I.; Nasir, E. *Flora of West Pakistan*; Department of Botany, University of Karachi: Karachi, Pakistan, 1971.
31. Rahman, A.; Khan, N.; Ali, K.; Ullah, R.; Khan, M.E.H.; Jones, D.A.; Rahman, I.U. Plant Species Classification and Diversity of the Understory Vegetation in Oak Forests of Swat, Pakistan. *Appl. Sci.* **2021**, *11*, 11372. [\[CrossRef\]](#)
32. Zhou, W.; Han, G.; Liu, M.; Li, X. Effects of soil pH and texture on soil carbon and nitrogen in soil profiles under different land uses in Mun River Basin, Northeast Thailand. *PeerJ* **2019**, *7*, e7880. [\[CrossRef\]](#)
33. Thomas, G.W. Exchangeable cations. In *Methods of Soils Analysis*; Page, A.L., Millar, R.H., Keeney, D.R., Eds.; Part 1; American Society of Agronomy: Madison, WI, USA, 1982; pp. 159–166.
34. Murphy, J.; Riley, J.P. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta* **1962**, *27*, 31–36. [\[CrossRef\]](#)
35. Stubbins, A.; Dittmar, T. Low volume quantification of dissolved organic carbon and dissolved nitrogen. *Limnol. Oceanogr. Methods* **2012**, *5*, 347–352. [\[CrossRef\]](#)
36. Orłóci, L. An agglomerative method for classification of plant communities. *J. Ecol.* **1967**, *55*, 193–206. [\[CrossRef\]](#)
37. Ter Braak, C.J. The analysis of vegetation-environment relationships by canonical correspondence analysis. *Vegetation* **1987**, *69*, 69–77. [\[CrossRef\]](#)
38. Skinner, W.R.; Jefferies, R.L.; Carleton, T.J.; Abraham, R.R.D.K. Prediction of reproductive success and failure in lesser snow geese based on early season climatic variables. *Glob. Change Biol.* **1998**, *4*, 3–16. [\[CrossRef\]](#)
39. Lepš, J.; Šmilauer, P. *Multivariate Analysis of Ecological Data Using CANOCO*; Cambridge University Press: Cambridge, UK, 2003.
40. Pino, J.; Font, X.; de Cáceres, M.; Molowny-Horas, R. Floristic homogenization by native ruderal and alien plants in north-east Spain: The effect of environmental differences on a regional scale. *Glob. Ecol. Biogeogr.* **2009**, *18*, 563–574. [\[CrossRef\]](#)



41. McKinney, M.L. Species introduced from nearby sources have a more homogenizing effect than species from distant sources: Evidence from plants and fishes in the USA. *Divers. Distrib.* **2005**, *11*, 367–374. [CrossRef]
42. Qian, H.; Ricklefs, R.E. The role of exotic species in homogenizing the north American flora. *Ecol. Lett.* **2006**, *9*, 1293–1298. [CrossRef]
43. Olden, J.D.; Rooney, T.P. On defining and quantifying biotic homogenization. *Glob. Ecol. Biogeogr.* **2006**, *15*, 113–120. [CrossRef]
44. Ricklefs, R.E.; Guo, Q.; Qian, H. Growth form and distribution of introduced plants in their native and non-native ranges in Eastern Asia and North America. *Divers. Distrib.* **2008**, *14*, 381–386. [CrossRef]
45. Qian, H.; Guo, Q. Linking biotic homogenization to habitat type, invasiveness and growth form of naturalized plants in North America. *Divers. Distrib.* **2010**, *16*, 119–125. [CrossRef]
46. Milchunas, D.G.; Salsa, O.E.; Lauenroth, W.K. A generalized model of the effects of grazing by large herbivores on grassland community structure. *Am. Nat.* **1988**, *132*, 87–106. [CrossRef]
47. Tappeiner, J.; Zasada, J.; Ryan, P.; Newton, M. Salmonberry clonal and population structure: The basis for a persistent cover. *Ecology* **1991**, *72*, 609–618. [CrossRef]
48. Timsina, B.B.B.; Shrestha, M.B.; Rokaya, Z.M.; Münzbergová, Z. Impact of *Parthenium hysterophorus* L. invasion on plant species composition and soil properties of grass land communities in Nepal. *Flora* **2011**, *206*, 233–240. [CrossRef]
49. Khan, N.; Bibi, K.; Ullah, R. Distribution pattern and ecological determinants of an invasive plant *Parthenium hysterophorus* L., in Malakand division of Pakistan. *J. Mt. Sci.* **2020**, *17*, 1670–1683. [CrossRef]
50. Paterson, I.D.; Hoffmann, J.H.; Klein, H.; Naser, S.; Mathenge, C.W.; Zimmermann, H.G. Biological control of cactaceae in South Africa. *Afr. Entomol.* **2011**, *19*, 230–246. [CrossRef]
51. Hejda, M.; Pyšek, P. What is the impact of *Impatiens glandulifera* on species diversity of invaded riparian vegetation? *Biol. Conserv.* **2006**, *132*, 143–152. [CrossRef]
52. Oduor, A.M.; Long, H.; Fandohan, A.B.; Liu, J.; Yu, X. An invasive plant provides refuge to native plant species in an intensely grazed ecosystem. *Biol. Invasions* **2018**, *20*, 2745–2751. [CrossRef]
53. Ogbazghi, W.; Stillhardt, B. *Sustainable Land Management a Textbook with a Focus on Eritrea*; Geographica Bernensia and Hamelmalo Agricultural College: Bern, Switzerland, 2011.
54. Bein, E.; Habte, B.; Jaber, A.; Birnie, A.; Tengnas, B. *Useful Trees and Shrubs in Eritrea*; Regal Press Limited: Nairobi, Kenya, 1996.
55. Davis, M.A.; Grime, J.P.; Thompson, K. Fluctuating resources in plant communities: A general theory of invasibility. *J. Ecol.* **2000**, *88*, 528–534. [CrossRef]
56. Novoa, A.; Le Roux, J.J.; Robertson, M.P.; Wilson, J.R.; Richardson, D.M. Introduced and invasive cactus species: A global review. *AoB Plants* **2015**, *7*, plu078. [CrossRef]
57. Vilà, M.; Espinar, J.L.; Hejda, M.; Hulme, P.E.; Jarošík, V.; Maron, J.L.; Pergl, J.; Schaffner, U.; Sun, Y.; Pyšek, P. Ecological impacts of invasive alien plants: A meta-analysis of their effects on species, communities and ecosystems. *Ecol. Lett.* **2011**, *14*, 702–708. [CrossRef]
58. Eaton, W.D.; Farrell, R.E. Catabolic and genetic microbial indices, and levels of nitrate, ammonium and organic carbon in soil from the black locust (*Robinia pseudo-acacia*) and tulip poplar (*Liriodendron tulipifera*) trees in a Pennsylvania forest. *Biol. Fertil. Soils* **2004**, *39*, 209–214. [CrossRef]
59. Morgan, E.C.; Overholt, W.A.; Sellers, B. Wildland Weeds: Paper Mulberry, *Broussonetia papyrifera*. Publication #ENY-702. Series of the Entomology and Nematology Department, Florida Co-Operative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. 2019. Available online: <https://edis.ifas.ufl.edu/in498> (accessed on 22 August 2020).
60. Ghersa, C.M.; de la Fuente, E.; Suarez, S.; Leon, R.J.C. Woody species in the Rolling Pampa grasslands, Argentina. *Agric. Ecosyst. Environ.* **2002**, *88*, 271–278. [CrossRef]
61. Bosu, P.P.; Apetorgbor, M.M.; Nkrumah, E.E.; Bando, K.P. The impact of *Broussonetia papyrifera* (L.) Vent. on community characteristics in the forest and forest–savannah transition ecosystems of Ghana. *Afr. J. Ecol.* **2013**, *51*, 528–535. [CrossRef]
62. Malik, R.N.; Husain, S.Z. *Broussonetia papyrifera* (L.) L'h 'er. Ex Vent.: An environmental constraint on the Himalayan foothills' vegetation. *Pak. J. Bot.* **2007**, *39*, 1045–1053.
63. Monemizadeh, Z.; Ghaderi-Far, F.; Sadeghipour, H.R.; Siahmarguee, A.; Soltani, E.; Torabi, B.; Baskin, C.C. Variation in seed dormancy and germination among populations of *Silybum marianum* (Asteraceae). *Plant Species Biol.* **2021**, *36*, 412–424. [CrossRef]
64. Kaur, A.; Kaur, S.; Singh, H.P.; Batish, D.R.; Kohli, R.K. Phenotypic variations alter the ecological impact of invasive alien species: Lessons from *Parthenium hysterophorus*. *J. Environ. Manag.* **2019**, *241*, 187–197. [CrossRef] [PubMed]
65. Sharma, A.; Batish, D.R.; Singh, H.P.; Jaryan, V.; Kohli, R.K. The impact of invasive *Hyptis suaveolens* on the floristic composition of the peri urban ecosystems of Chandigarh, northwestern India. *Flora* **2017**, *233*, 156–162. [CrossRef]
66. Anning, A.K.; Gyamfi, B.; Effah, A.T. *Broussonetia papyrifera* controls nutrient return to soil to facilitate its invasion in a tropical forest of Ghana. *J. Plant Ecol.* **2018**, *11*, 909–918. [CrossRef]
67. McEwan, R.W.; Arthur, M.A.; Alverson, S.E. Throughfall chemistry and soil nutrient effects of the invasive shrub *Lonicera maackii* in deciduous forests. *Am. Midl. Nat. J.* **2012**, *168*, 43–55. [CrossRef]
68. Yapi, T.S.; O'Farrell, P.J.; Dziba, L.E.; Esler, K.J. Alien tree invasion into a South African montane grassland ecosystem: Impact of *Acacia* species on rangeland condition and livestock carrying capacity. *J. Biodivers. Ecosyst. Serv. Environ. Manag.* **2018**, *14*, 105–116. [CrossRef]



- 
69. Nicolescu, V.N.; Hernea, C.; Bakti, B.; Keserű, Z.; Antal, B.; Rédei, K. Black locust (*Robinia pseudoacacia* L.) as a multi-purpose tree species in Hungary and Romania: A review. *J. For. Res.* **2018**, *29*, 1449–1463. [[CrossRef](#)]