sustainability

Article

Invasive Species as Rivals: Invasive Potential and Distribution Pattern of *Xanthium strumarium* L.

Rafi Ullah [1], Nasrullah Khan [1], Nina Hewitt [2], Kishwar Ali [3,*], David Aaron Jones [4] and Muhammad Ezaz Hasan Khan [3]

1 Department of Botany, University of Malakand, Dir Lower, Chakdara 18800, Khyber Pakhtunkhwa, Pakistan; rafiullah198773@gmail.com (R.U.); nasrullah.uom@gmail.com (N.K.)
2 Department of Geography, Vancouver Campus, University of British Columbia, 240A-1984 West Mall, Vancouver, BC V6T 1Z2, Canada; nina.hewitt@ubc.ca
3 College of General Education, University of Doha for Science and Technology, Arab League Street, Doha 24449, Qatar; mdezazhasan.khan@udst.edu.qa
4 College of Health Sciences, University of Doha for Science and Technology, Arab League Street, Doha 24449, Qatar; davidaaron.jones@udst.edu.qa
* Correspondence: kishwar.ali@udst.edu.qa or kishwar.ali@cna-qatar.edu.qa

Abstract: *Xanthium strumarium* L. is a globally successful invasive herb that has had significant negative ecological, economic and social impacts in many world regions. The present study was therefore conducted to evaluate the invasive potential and spatial distribution patterns of *X. strumarium* in heavily invaded plant communities of the semiarid regions of northern Pakistan. Investigations were based on data from 20 plants grown in the Herbarium at the University of Malakand, and from observations in 450 plots distributed across 45 stands representing habitats across Northern Province including open fields, hillocks and abandoned areas in both urban and rural areas. Multivariate analysis identified elevation, organic matter and organic carbon as the environmental variables most associated with communities invaded by *X. strumarium*. Increased soil silt was positively associated and available water was negatively associated with *X. strumarium*–invaded communities. These key environmental characteristics allowed us to identify four main associations: Group I: *X. strumarium-C. sativa*, Group II: *X. strumarium-P. hysterophorus*, Group III: *X. strumarium-A. aspera* and Group IV: *X. strumarium-C. sativa*. Other invasive species were observed, either exotic, such as *P. hysterophorus*, or indigenous, such as *C. sativa* and *D. inoxia*, often co-occurring and responding similarly to these factors. The results suggest that high temperature with drought stress could be a determinant of increasing population at lower elevations, whereas colder climates with adequate moisture are related to reduced populations at higher elevations, near the species' upper range limits. It is recommend that the inclusion of appropriate, additional soil and climatic variables in species distribution models be implemented in order to better explain species' ecological niches and help guide conservation and protection plans for native plant communities.

Keywords: *X. strumarium*; community structure; co-occurrence; invasive species; plant invasions

check for updates

Citation: Ullah, R.; Khan, N.; Hewitt, N.; Ali, K.; Jones, D.A.; Khan, M.E.H. Invasive Species as Rivals: Invasive Potential and Distribution Pattern of *Xanthium strumarium* L.. *Sustainability* **2022**, *14*, 7141. https://doi.org/10.3390/su14127141

Academic Editor: Bernhard Huchzermeyer

Received: 15 May 2022
Accepted: 2 June 2022
Published: 10 June 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The recent era has witnessed enhanced trade, transport and tourism, industrial expansion, technological advancement and increasing urbanization [1]. These factors place natural ecosystems under increasing pressure to provide ecosystem services to rapidly expanding human populations and further facilitate the introduction and invasion of exotic species [2]. The rapid increase in human transport and goods globally has facilitated the spread of non-native species and their expansion into new habitats such that invasive species are now considered to be among the leading causes of species extinction and biodiversity loss worldwide [3]. Invasive plants affect evapotranspiration, causing severe threats to sustainable water supply [4] and ecosystem services such as resources and energy [5]. Invasive species may have deleterious impacts on native populations via several mechanisms, including genetic effects, pathogen introduction and habitat degradation [6,7]. The ability to colonize new habitats and resist disease and pests have been identified in traits which promote the spread of invasive plant species, including effective propagule production and dispersal via seeds and vegetative structures, early flower and seed formation and other phenological advantages relative to native species [8,9]. When exotic species out-compete native plants for nutrients, light and shelter, they form monotypic stands that pre-empt native flora [10] and contribute to altered ecosystem structure and function [11].

Invasive plant species spread rapidly across roads, railway tracks, cities and rural areas, resulting in community homogenization [12]. Biotic homogenization changes diverse populations within an area to become progressively similar and is a significant factor that affects the establishment of invasive species in an ecosystem [13]. They are regarded as a valuable resource because of their capacity to adapt to new environmental factors and disturb native plant communities [14]. An invasive species may be able to invade and spread in a new habitat despite biotic and abiotic filters [15]. Environmental parameters of any area, notably temperature, relative humidity, day length, and geographical and topographic variables, operate as an abiotic filter for newly invading invaders [16]. The filter's efficiency is determined by how closely environmental conditions correspond to the species' native and invaded habitats [17]. An alien species' phenology does not change if the new range's environment and habitat are identical to its original range [18]. The alien species will produce seeds, propagules and vegetative growth, and flower as it does in its native range [17]. In the opposite situation, the invasive species' success is determined by a combination of the environmental fluctuations and the species' inherent capacity to flower [19].

Research outlining the impacts of invasive species on ecological systems will be critical in protecting and conserving native species and essential ecosystem processes [20]. Pakistan has unique and valuable biodiversity owing to its particular geography, in terms of, for example, topography, climate and soils. This geography includes features such as a tropical marine coastline in the south, a strong elevation gradient inland due to mountain orogeny, and the influence of the moisture-bearing South Asian Monsoons and the Drier Westerly winds [21]. However, being a largely agricultural nation, Pakistan struggles socio-economically with low crop productivity and inefficiencies in its agricultural system [22]. It is vulnerable to limits on its ability to supply food crops to its inhabitants. Invasive species have thus been introduced to meet the increasing demand for foodstuffs, causing pressure on native plant communities [23].

More than 6000 vascular plants have been reported from Pakistan, of which 5600 have been described [24]. In addition, 700 invasive plant species have also been listed as posing a severe threat to native plant communities [25]. In Khyber Pakhtunkhwa, 16 invasive species were reported, including *Trianthema portulacastrum* L. *Amaranthus viridis* L. *Carthamus oxyacantha* M.B., Fl. Taur. Cauc. *Conyza bonariensis* L. Cronquist in Bull. Tor. Bot. Club, *Xanthium strumarium* L., *Asphodelus tenuifolius Cavan.* L., *Asphodelus tenuifolius Cavan.* L., *Eucalyptus camaldulensis Prosopis juliflora* L., *Avena fatua* L. and *Imperata cylindrica* (L.) *Phragmites australis* (Cav.) Trin. ex Stued. *Gallium aparine* L. [26]. *Xanthium strumarium* L. (Asteraceae), also known by many vernacular names (e.g., cocklebur, *lampourde glouteron*, ditchbur, clot bur, noogoora bur, sheep bur [27,28]), is an emerging invasive species in various districts of Khyber Pakhtunkhwa (KP), Pakistan [26]. *Xanthium* originates from South or Central America, from where it spreads into North America, invading riverways and shorelines and dispersing widely via hydrochory (via water) and zoochory (via animals) [29]. In North America, anthropogenic activity has added Eurasian strains, and cross-breeding has resulted in polyploidy and genetic variability in populations of different regions. The highest genetic variability in *Xanthium* is in Northeast North America, where tetraploid populations occur uniformly across the region [29].

The invasion of the *X. strumarium* in KP has significantly increased with the movement of Afghan refugees in the 1970s and has had pronounced effects on plant communities in general and crop plants, e.g., maize, soya bean, cotton and groundnuts, in particular [30]. The species is now a common weed across the region, affecting biodiversity. Its success is due to its invasive traits, i.e., adherent burs that spread via animals along waterways and land, prolonged seed viability and photo-intensity and production of allelopathic compounds [31,32].

In Pakistan, *X. strumarium* was first reported by Baloch et al. [33] as a host for insect pests. Since then, many studies have reported it as a weed species among different crops in Khyber Pakhtunkhwa, Pakistan [26,27]. A limited number of studies address the invasive potential of *X. strumarium* and its impacts on biodiversity [20,34–36], and even less attention to the associated environmental and topographic variables that facilitate invasion. The present research evaluated *X. strumarium* potential to impact the native communities of the area. In addition, we also considered the relationship of communities with environmental variables to investigate which factor sustains these communities. Therefore, this research examines *X. strumarium-dominated* plant communities and characterizes the environmental variables and soil parameters associated with the species to better understand the factors responsible for maintaining its populations and affecting invaded communities. The aim is to inform and address efforts to control and eradicate *X. strumarium*.

2. Materials and Methods

2.1. Study Area

2.1.1. Zones and Distribution Points

KP is one of the five administrative provinces of Pakistan (Figure 1). KP Environmental Protection Agency classified the province into four agro-ecological zones based on climate, precipitation, temperature, altitude and topography. Zone A includes mountainous areas of district Swat, Shangla, Dir, Bunir and Chitral. Zone B lies within the eastern mountainous sub-humid and wet mountainous regions and includes the districts of Abbottabad, Batagram, Mansehra, Kohistan, Haripur and Torghar. Zone C includes the central plain valley of Peshawar, Charsadda, Hangu, Karak, Nowshera, Bannu, Mardan, Kohat and Swabi.

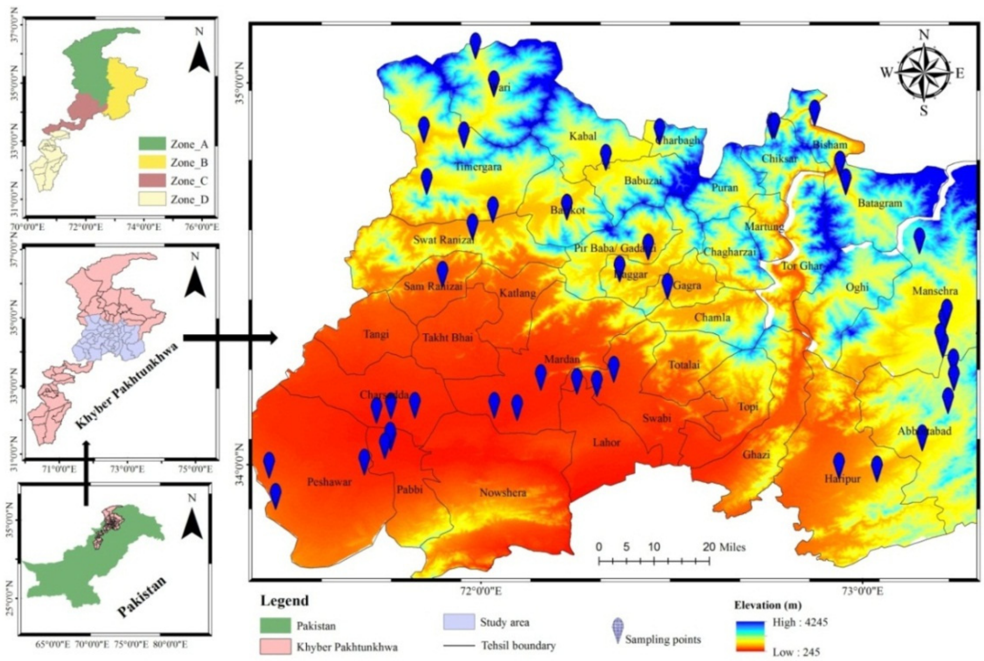

Figure 1. Study region in the Khyber Pakhtunkhwa province, Northern Pakistan, showing agro-ecological zones and distribution of *Xanthium strumarium* in the province.

Zone D includes the Piedmont plains and Suleiman, within the districts of Bannu, Lakki Marwat, Tank, Karak and Dera Ismail Khan [37]. Zones C and D are characteristically plains with agricultural fields that contribute to the livelihood of local people, adding 20% in GDP and 44% in labor potential to the province [37]. *X. strumarium* heavily invades and affects these two zones' agricultural fields and vegetation [25]. The sites sampled were located between 34.29° to 34.55° N and 71.84° to 72.62° E (Elev. 390 to 981 m asl; see Figure 1), covering the commonly invaded roadsides and abandoned areas in both urban and rural vicinities.

2.1.2. Climate, Physiography and Vegetation

The climate of the study area is temperate, with mean annual rainfall ranging from 384 mm to about 639 mm (Figure 2) and mean monthly temperatures ranging from 34.96 ± 1.36 °C to 0.67 ± 0.97 °C [38].

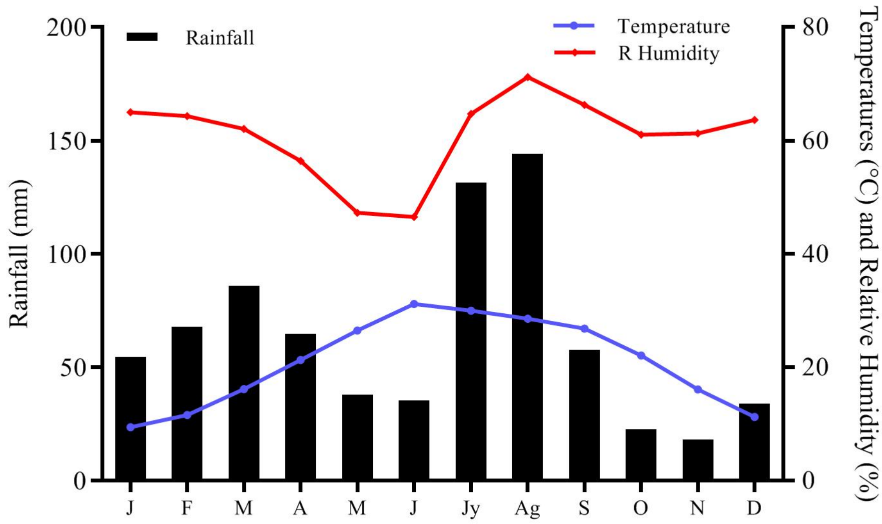

Figure 2. Important climate variables of the sampling sites.

The regional geology is classified into thirteen substrate types, aggregated from thirty-seven sub-categories based on bedrock lithology [39]. For example, the northern Indus suture zone mixes igneous, mafic and ultramafic rock sequences. The northern portions of the study area are predominantly volcanic rocks; the Khyber-Hazara zone is dominated by metamorphic complexes with rich mineral material, including diverse mineral ores [40].

Ecological communities in the region are complex and quite dissected partly due to the rugged and variable topography in this massive mountainous region of the Himalayan Hindu Kush (HHK) [37]. A variable and biodiverse flora and fauna are thus supported [41]. Plant communities include montane, alpine forests, dry coniferous forests and sub-tropical forests. Montane forests occur at elevations of 4000 m in Swat, Chitral and Hazara; Alpine and dry coniferous forests occur throughout, at elevations ranging from 3350–3360 m for alpine and 1525–3660 m for dry forests. Sub-tropical forests occur on south-facing slope aspects at elevations of 900–2000 m in the Himalayan range within the districts of Swat and Hazara [42].

2.2. *Study of Invasive Characteristics*

X. strumarium invasive traits were studied under experimental and field conditions. *X. strumarium* (n = 20 plants) was grown in the Botanical Garden of the University of Malakand Khyber Pakhtunkhwa, Pakistan. Characteristics known to predict invasiveness of a species were recorded, including the number of days required for seedling emergence, % age of seed germination, vegetative growth period and reproductive output, i.e., number of seeds and fruits produced per plant. In addition, important climatic indicators such as daily temperature, humidity, day length and precipitation, daily dew point temperature in

°C and daily ultraviolet index were recorded. *X. strumarium* dried fruits were collected to assess seed characteristics including average number of seeds per fruit (n = 2), determined by counting the seeds, and mean seed mass of 100 seeds (n = 50), determined by weighing the seeds on an electronic weighing balance. These data were also used to calculate a Discriminant Function [43], which serves as a basic screening tool to assess the invasive potential of woody species. The following formula calculates it:

$$\text{Discriminant Function} = 19.77 - 0.51\sqrt{M} - 3.14\sqrt{J} - 1.21S \tag{1}$$

where, M = mean seed mass (mg); J = minimum juvenile period (years); S = mean interval between large seed crops (years).

2.3. Field Studies of Invasive Species Distribution and Inter-Species Associations

Our field studies involved regular visits to collect vegetation data within 15 districts (Figure 1), where 45 *X. strumarium* dominated stands were randomly sampled. The data-set consists of 450 phytosociological plots ($45 \times 10 = 450$ plots), taken strictly according to floristic and structural homogeneity within sampled vegetation stands to provide a reasonable survey of the whole study area. The size of the plots varied between 3 m^2 to 5 m^2, with differences by a factor of up to five, considered acceptable by [44]. In each plot, density, frequency, cover, relative density, relative frequency, relative cover and Importance Values were calculated following the standard procedure [45]. Edge effects were reduced by excluding a 10-m buffer zone from the stand boundaries [46]. All plants were identified following Flora of Pakistan [47], following the nomenclature of plant taxa according to [48].

2.4. Ecological Impact Assessment

An additional survey was conducted to assess the ecological impact of *X. strumarium* on floristic composition and species diversity. Soil characteristics were further investigated to evaluate impacts of the species invasion on soil variables.

2.4.1. Impact on Diversity

A total of 450 plots invaded at varying intensities by *X. strumarium* were established, and the number of species (richness), density, cover, height and volume were calculated to compare species diversity and invasion effects. An inventory was prepared to list the species name, plant family and other floristic attributes following Flora of Pakistan [47]. Herbarium vouchers were deposited in the Department of Botany, University of Malakand Khyber Pakhtunkhwa, Pakistan. Three important ecological diversity indices, Species richness (S), Shannon-Wiener diversity index (H') and evenness index (E), were calculated based on species density following [49]. Species richness was measured as a simple count of species in the stand. The H' and E indices are calculated as:

$$H' = \sum_{i=1}^{S} pi\ \text{In}pi \tag{2}$$

$$E = \frac{H'}{\text{In}S} \tag{3}$$

where pi = proportion of the species (i) to total number of species, In = natural logarithm of pi and InS = natural logarithm of species richness.

2.4.2. Soil Assessment

To characterize soil properties in each *X. strumarium*-invaded stand, we obtained 3-kg soil from two opposite corners and at a mid-position of each stand with auger borings. Soil top layer is generally rich in nutrients, and consequently, samples were obtained over a depth of 0–30 cm [50], bulked, and mixed thoroughly to reduce heterogeneity following standard pedological procedures [46,51]. Soil pH was immediately determined in soil-water suspension (1:5 ratio) in the field by a digital pH meter and electrical conductivity by EC-meter. The physiochemical and textural nature of the soil was determined by air-drying and sieving the samples through a 2-mm sieve following U.S.D.A. methods [52]. The

Walkley–Black method was used to estimate organic matter, whereas total and organic carbon were determined by wet combustion with chromic acid digestion followed by dry combustion [53]. Total nitrogen was obtained by the micro-Kjeldahl technique, and available phosphorus (P^{2+}) and exchangeable potassium (K^+) were determined following [54]. Lime (Calcium carbonate; %) was calculated using the geometric method and CO_2 evolution was measured geometrically following [52]. We assessed additional soil parameters including available water (AW), field capacity (FC), wilting and saturation point (WSP), conductivity (µs/cm) and bulk density (BD) following [55] using an online calculator (https://www.nrcs.usda.gov (accessed on 15 October 2021)). The hydrometer method determined textural properties such as sand, clay and percent silt distribution [56] at Swat Agriculture Research Institute (SARI).

2.5. Data Analysis

Phytosociological data of species in the 45 stands and corresponding environmental variables were data-banked for analysis and interpretation. The relative phytosociological attributes were transformed into importance value index (IVI) according to [57]. The classification of vegetation communities was evaluated using Ward's agglomerative method by opting for Euclidean distance in the package PC-ORD ver. 6.0 [58]. After the numerical classification, the species occurring in each stand were assigned to a phytosociological group. To evaluate whether a certain species could be considered as diagnostic of a class, we consulted recent literature [45,59–62]. Then, we summed the transformed relative phytosociological values of the diagnostic species in plots to provide a suitable phytosociological locus to the stand's groups obtained by numerical classification. The non-parametric Kruskal–Wallis test analyzed the indices of phytosociological stands from the resulting clusters.

The relationship between floristic variation within *X. strumarium* dominated vegetation and environmental variables were analyzed using Canonical correspondence analysis (CCA). Four topographic variables and 16 soil properties were used in CCA, whereas post hoc interpretation of the CCA ordination axes was statistically evaluated using a Monte Carlo permutation test. In addition, vectors of the significant variables were visualized in the ordination diagram. Finally, the weighted average values of significant variables in the different vegetation types were represented by box plots. All quantitative vegetation and environmental data analyses were performed in Graph Pad Ver 7.0 [63] and MS Excel (2010).

3. Results

3.1. Invasive Potential of *X. strumarium*

The germination percentage of *X. strumarium* was found to be 78%, indicating a high reproductive capacity and potential for invasion. The plant produces two seeds per bur, where the seed mass was found to be 14.9 ± 5.76 g per 100 seeds. The other phenological and climatic parameters are summarized in Table 1.

The seeds are typically dispersed exozoochorously by animals, in this case by domesticated sheep and goats, assisted by sticky burs (Figure 3). Species' discriminant Function, an index of invasion potential, was determined to be 12.02 ± 0.52.

Table 1. Climatic parameters and different associated traits of *Xanthium strumarium* related to invasive behavior.

Climatic Parameter	DLH	ADH (%)	ADR	ADMNT	ADMXT	ADMT	ADDP	DUVI
	12:14 ± 0.06	53.13 ± 13.93	0.43 ± 0.6	7.9 ± 4.02	34.1 ± 4.7	23.6 ± 3.83	8.23 ± 4.23	3 ± 2.56
Trait Parameter	DE	DI	DD	NI/P	NB/P	BB/50	SB/100	SBB/50
	5.1 ± 0.78	41.65 ± 3.73	131 ± 12.78	400 ± 66	324 ± 56	25.5 ± 5	14.9 ± 5.76	39.45 ± 10.5

Note: DLH (Day length in hours); ADH % (Average daily humidity in percentage); ADR (Average daily rainfall in millimeters); ADMNT (Average daily minimum temperature in °C); ADMXT (Average daily maximum temperature in °C); ADMT (Average daily mean temperature in °C); ADDP (Average daily dew point in °C); DUVI (Daily ultraviolet index); DE (Days to emergence); DI (Days to inflorescence); DD (Days to drying); NI/P (number of inflorescence per plant); NB/P (number of burs per plant); BB/50 (bur biomass in g/50); SB/100 (seed biomass in g/100); SBB/50 (Seeds and bur biomass in g/50).

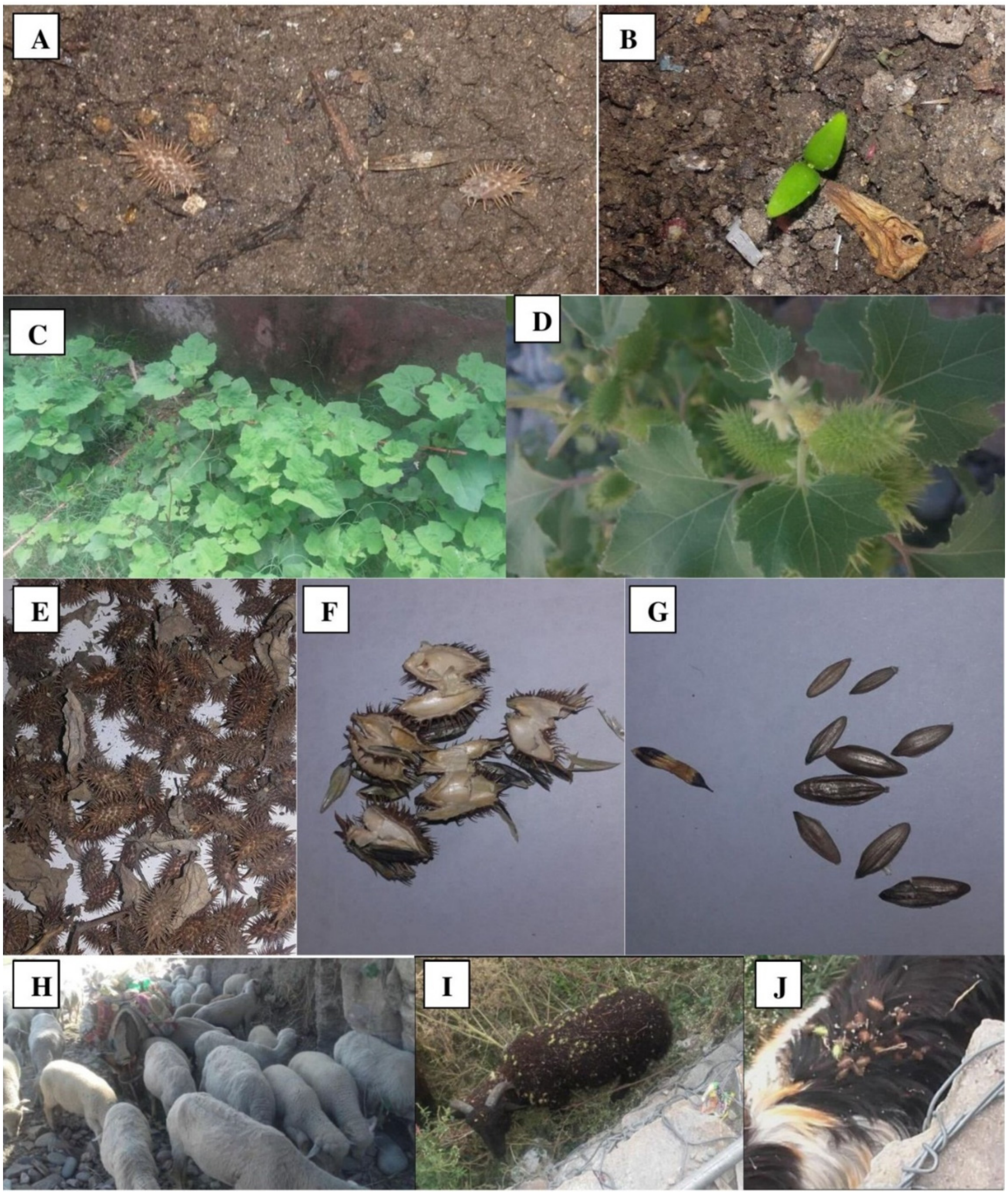

Figure 3. Phenological phases and invasive spreading of *Xanthium strumarium* i.e., (**A**) (Burs for germination); (**B**) (First emergence); (**C**) (Vegetative phase); (**D**) (reproductive phase i.e., inflorescence and burs); (**E**) (collected burs); (**F**) (Empty burs); (**G**) (Developed seeds); (**H**) (Nomads and domestic animals); (**I**) (Sheep having sticky burs); (**J**) (Goat with sticky burs).

3.2. Local Distribution of X. strumarium

X. strumarium-invaded communities were classified into four ecologically meaningful groups depending on varying habitats and species composition (Figure 4). These relatively discrete phytosociological groups have substantial floristic bulk of species composition, which differs significantly in the average Importance Value percentage (*F*-value 6.47; $p < 0.01$; Table 2). Nevertheless, the four groups differed significantly in terms of the IVI of diagnostic species (*F*-value 53.79; $p < 0.001$) (Table S1). In particular, the second most dominant species in all the four groups are different unusually except in group I and IV which are similar but slightly different in terms of IVI, i.e., 12.94 ± 1.14 and 18.22 ± 3.01, respectively for *Cannabis sativa*. In addition, the floristic assemblage in group-I is characterized by *Xanthium-Cannabis*, with a real predominance of *Chenopodium album* (7.22%) and *Cynodon dactylon* (Table S1). The distinction of this cluster was further supported by the significant prominence of an exotic invasive species, *Parthenium hysterophorus* (6.15%), and native invasive *Silybum marianum* (3.90%) as well as *Amaranthus viridis* (4.43%), respectively.

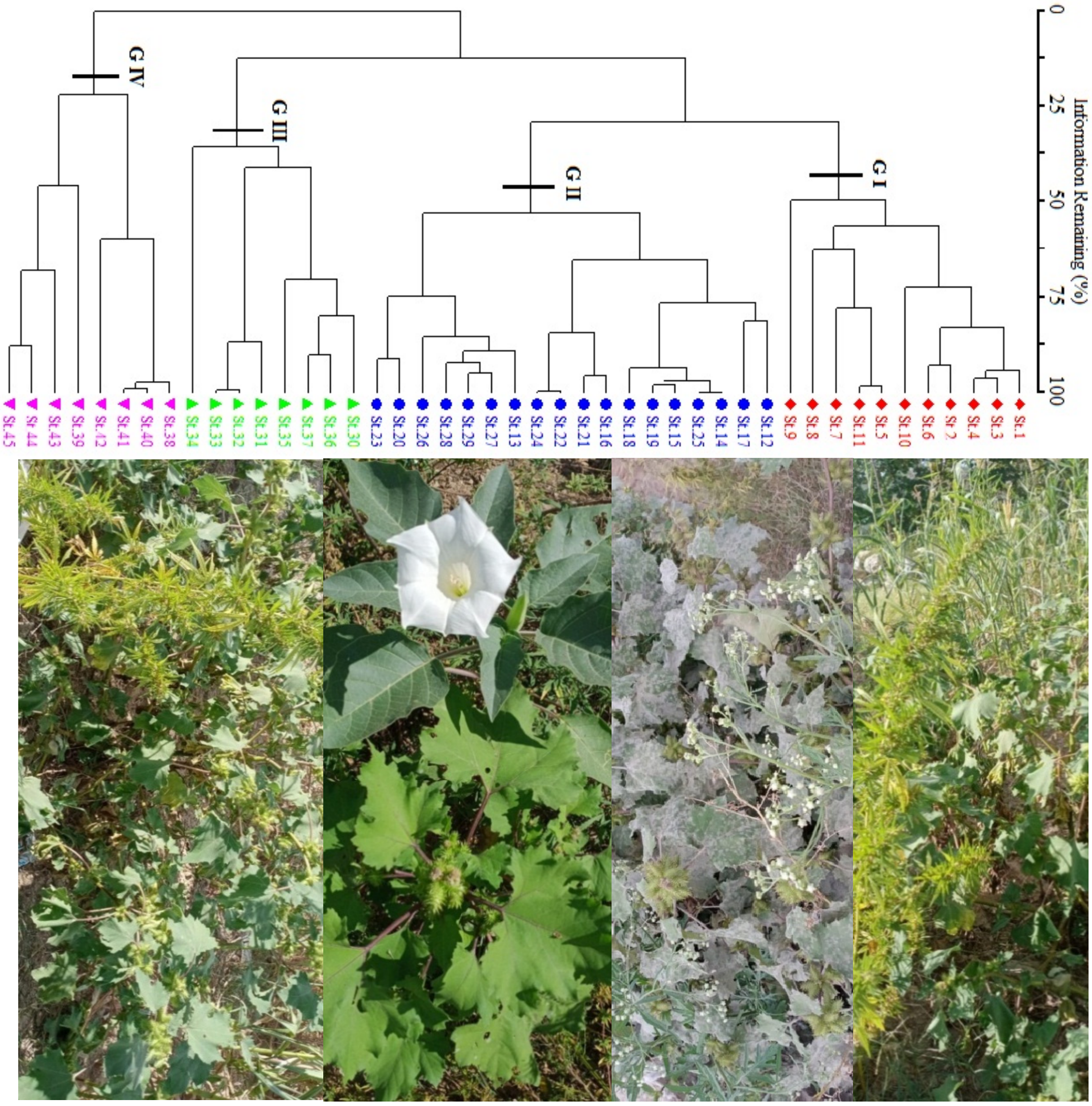

Figure 4. Cluster dendrogram of the 45 stands (450 plots) dominated *X. strumarium.* Note: Group I (community of *X. strumarium-C. sativa*); Group II (community of *X. strumarium-P. hysterophorus*); Group III (community of *X. strumarium-D. metel*); Group IV (community of *X. strumarium-C. sativa*); G (Group); St. (Stand number).

Table 2. Vegetation characteristics following a period of *X. strumarium* invasion and potential stabilization in Khyber Pakhtunkhwa, Pakistan.

Communities	Species	AH/Plant	AIVI (%)	H-Index	J-Index	AD/st.	AC/st.	AV/st.
Group-I	29	26.4 ± 4.3	39.7 ± 1.42 a	1.67 ± 0.11 a	0.78 ± 0.02	34.8 ± 4 a	65 ± 27 a	24.9 ± 2 a
Group-II	28	23.6 ± 1.2	45.4.94 ab	1.44 ± 0.04 ab	0.74 ± 0.01	38.3 ± 2.0 a	38.6 ± 3 ab	25.5 ± 1.9 a
Group-III	26	31.9 ± 6	47.0 ± 2.3 b	1.42 ± 0.09 b	0.67 ± 0.04	48 ± 7.8 ab	95.4 ± 43 a	39 ± 7.4 b
Group-IV	18	32.0 ± 4.1	50.9 ± 3 b	1.19 ± 0.11 c	0.71 ± 0.03	50 ± 7.8 ab	84.4 ± 38 a	31.6 ± 4.4 b
F-value	–	1.1584	6.47	5.45	2.30	3.184	2.512	2.920
p-value	–	0.3402	0.001	0.0029	0.090	0.03	0.05	0.04

Note: AH (average height); A.IVI (average importance values index); H-index (Shannon-wiener diversity); J-index (Equitability or Evenness index); AD/ha (average density ha^{-1}); AC/ha (average cover ha^{-1}); AV/ha (average volume ha^{-1}). Column wise different letters indicate significant difference at $p < 0.05$

The group-II was distinguished by the overwhelming presence of invasive exotic *P. hysterophorus* (13.61%) and *C. album* (4.66%), respectively, with several other new individuals from their preceding and proceeding groups, i.e., groups I, III and IV. The group-III is an *X. strumarium-D. innoxia* community based on IVI dominance (Table 2). None of the species except *Carthamus oxycantha* showed IVI greater than 5%, while *Eryngium coereculum* and *Amaranthus spinosus* (IVI ≤ 3%) were distinct species of the group. Surprisingly, the vegetation belongs to group-IV, a community of *X. strumarium* and *C. sativa* that seems similar to group-I. However, owing to the floristic heterogeneity (Table S1), the syntaxonomical position of stands in group-IV should not be mixed with the first phytosociological group and is perhaps a distinct vegetation type. Group-IV, hereafter reported as a community of *X. strumarium* and *C. sativa*, showed a distinct floristic composition, having IVI of *D. innoxia* (9.78%), *Verbascum thapsus* (5.29%) and *P. hysterophorus* (2.56%). The group-IV could be tentatively placed in a separate category based on its floristic composition, as recently proposed by [64] and subsequently accepted by [65]. The floristic composition of the *X. strumarium* and *C. sativa* community (Group-IV) differed from the former groups owing to the reduced IVI of some constituent species and the prominence of new species such *Tagetes minuta* (IVI = 2.98%) and *Justicia adhatoda* (IVI = 1.26%).

3.3. *X. strumarium Invasion Impacts on Diversity*

Overall, 50 species distributed in 48 genera and 25 families were recorded in 45 vegetation stands (Table S2). The dominant angiosperm families were Asteraceae (13 species, 13 genera) and Amaranthaceae (4 species, 3 genera), whereas the contribution of Solanaceae, Brassicaceae and Fabaceae were 3 species and 3 genera each, altogether accounting for 60% of the total genera and species respectively. Based on habit, the community consists of 54% annuals that were significantly more common than perennials (36%) and accounted for 90% of the total plant species. The remaining 10% of species were biennial, annual/biennial or annual/perennial, but were not homogeneously distributed in the region. Analysis of the historic geographical spectrum or origin of plants shows a high proportion of invasive plant species (42%) relative to native (26%) and naturalized (20%) species, whereas cultivated and casual aliens comprised rare taxa. Generally, the vegetation exhibited wide phytogeographically affinities, predominantly representing species native to South America (22%), Europe (20%), Tropical America and Pantropical (6% each) regions. Eighteen other regions contributed low species richness, including native species (26%) which were more important from a phytogeographical perspective (Table S2). The average species richness, Shannon–Wiener index, coverage, density and volume of the plants within the communities ($p < 0.001$) decreased with increasing importance values, highlighting the invasiveness of *X. strumarium* and its invisibility in the region (Table 2).

3.4. *Impacts on Soil and Associated Environmental Variables*

The various environmental factors associated with *X. strumarium* communities are depicted in Table 3. In communities, elevation ranged from 390 m to 981 m (Figure 5b), which differed significantly (*H*-statistic 13.66; *p*-value = 0.0034) and correlated positively with IVI ($r = 0.247$; $p < 0.05$) and density ha^{-1} ($r = 0.281$; $p < 0.05$). Geophysical coordinates also showed marked differentiation of latitude and longitude (Figure 5a,c) that negatively affects *X. strumarium.* Cover/hectare and volume/hectare ($r = -0.278$; $p < 0.05$). The soil of invaded communities was relatively thick (up to 90 cm in depth) and generally well drained, with flat to gently sloping terrain. Soil texture was typically sandy-loam or clay-loam, with a clay fraction showing a significant increase (*H*-statistic 7.71; *p*-value = 0.0066) with depth in the soil profile.

Table 3. Mean (±) standard deviation (SD) of twenty-two different environmental variables for the vegetation stands associated with each of the four clusters. Significant difference was computed by using a non-parametric Kruskal-Wallis test followed by Tukey HSD.

Factors	Groups I	II	III	IV	*H*-Values	*p*-Values
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE		
Elev	390.4 ± 87	843.1 ± 70	614.3 ± 123	981.1 ± 146	13.663	0.0034 **
N°	34.29 ± 0.11	34.16 ± 0.06	34.3 ± 0.16	34.55 ± 0.05	11.972	0.007 **
E°	71.84 ± 0.17	72.62 ± 0.12	71.9 ± 0.19	72.3 ± 0.15	12.538	0.005 **
AA	142.27 ± 32	193.72 ± 22	129.2 ± 37.9	126 ± 37.67	3.885	0.274
Cl%	24.76 ± 3.7	32.70 ± 2.5	21.7 ± 1.44	26.07 ± 3.43	7.17	0.066 *
Si%	35.88 ± 5.9	36.33 ± 3	44.3 ± 4.89	43.2 ± 6.31	4.497	0.212
Sa%	39.35 ± 5.4	30.96 ± 3	33.8 ± 4.77	30.7 ± 4.36	2.195	0.532
pH1:5	6.74 ± 0.13	6.91 ± 0.09	6.7 ± 0.092	6.71 ± 0.15	2.3041	0.511
OM%	1.02 ± 0.18	1.67 ± 0.1	1.48 ± 0.23	1.18 ± 0.16	5.672	0.128
OC%	0.57 ± 0.10	0.97 ± 0.1	0.85 ± 0.13	0.68 ± 0.09	2.458	0.076
L%	10.02 ± 1.0	8.22 ± 0.4	8.33 ± 0.95	8.82 ± 1.88	2.905	0.406
TC%	1.5 ± 0.10	1.98 ± 0.1	1.87 ± 0.13	1.7 ± 0.09	2.458	0.076
N	0.030 ± 0.007	0.064 ± 0.01	0.052 ± 0.019	0.030 ± 0.009	1.082	0.781
P	4.72 ± 0.33	4.65 ± 0.2	5.11 ± 0.59	5.04 ± 0.43	1.034	0.793
K	114.18 ± 9.4	102.2 ± 8.8	110.87 ± 14.81	100.2 ± 13.4	1.580	0.663
EC	249.72 ± 36	324.2 ± 20.67	308.62 ± 32.75	334.1 ± 13.3	7.759	0.051 *
TDS	159.82 ± 23	207.50 ± 13.2	197.52 ± 10.96	213.8 ± 8.53	7.759	0.051 *
WP	0.153 ± 0.017	0.18 ± 0.012	0.13 ± 0.0058	0.154 ± 0.01	7.651	0.053 *
FC	0.28 ± 0.018	0.328 ± 0.01	0.27 ± 0.008	0.301 ± 0.013	7.232	0.064 *
BD	1.38 ± 0.02	1.32 ± 0.016	1.38 ± 0.014	1.35 ± 0.017	6.481	0.090 *
SP	0.47 ± 0.009	0.49 ± 0.006	0.47 ± 0.0054	0.487 ± 0.0066	6.388	0.094 *
AW	0.13 ± 0.008	0.14 ± 0.005	0.14 ± 0.0085	0.14 ± 0.0068	1.686	0.639

Note: Elev (Elevation in m); N° (North); E° (East); Cl% (Clay percentage); Si% (Silt percentage); Sa% (Sand percentage); pH (Protenz Hydrogen); OM% (Organic Matter percentage); OC% (Organic carbon percentage) TC% (Total carbon percentage); L% (Lime percentage); N (Nitrogen percentage); P (Phosphorus in mg/Kg); K (Potassium in mg/kg) EC (Electrical conductivity µs/cm); TDS (Total dissolve solid ppm, 640 Scale,); WP (Wilting Point at 1500 kPa); FC (Field capacity at 33 kPa); BD (Bulk Density in g/cm3); SP (Saturation at 0 kPa); AW (Available water); * ($p < 0.05$); ** ($p < 0.01$).

Soil pH was slightly acidic in all the vegetation types, probably due to similar parental material (Igneous rocks). The values of organic matter, carbon contents and total carbon decreased from species-rich to species-poor vegetation types and correlated positively ($r = 0.297$; $p < 0.05$) with density ha^{-1}. The soil percent lime varies (8.22–10.02%) and exhibited negative relationships with Importance values ($r = -0.214$; $p < 0.05$), density ($r = -0.427$; $p < 0.01$) and volume ha^{-1} ($r = 0.295$; $p < 0.05$), whereas the nitrogen and potassium content showed a similar trend and negatively affecting vegetation density ($r = -0.251$; $p < 0.05$) in the communities (Table S3). The available phosphorus was comparatively very high, which was always below the detection limit of 2.5 mg/kg in other natural plant communities, as reported by [42] for *Dodonaea viscosa*. Several soil properties, such as electric conductivity, total dissolved salt, wilting point, field capacity, bulk density and saturation point, showed statistically significant differences and decreased from species-rich to species-poor vegetation types (Table 2) but did not appear to play a major role in shaping these or other vegetation characteristics.

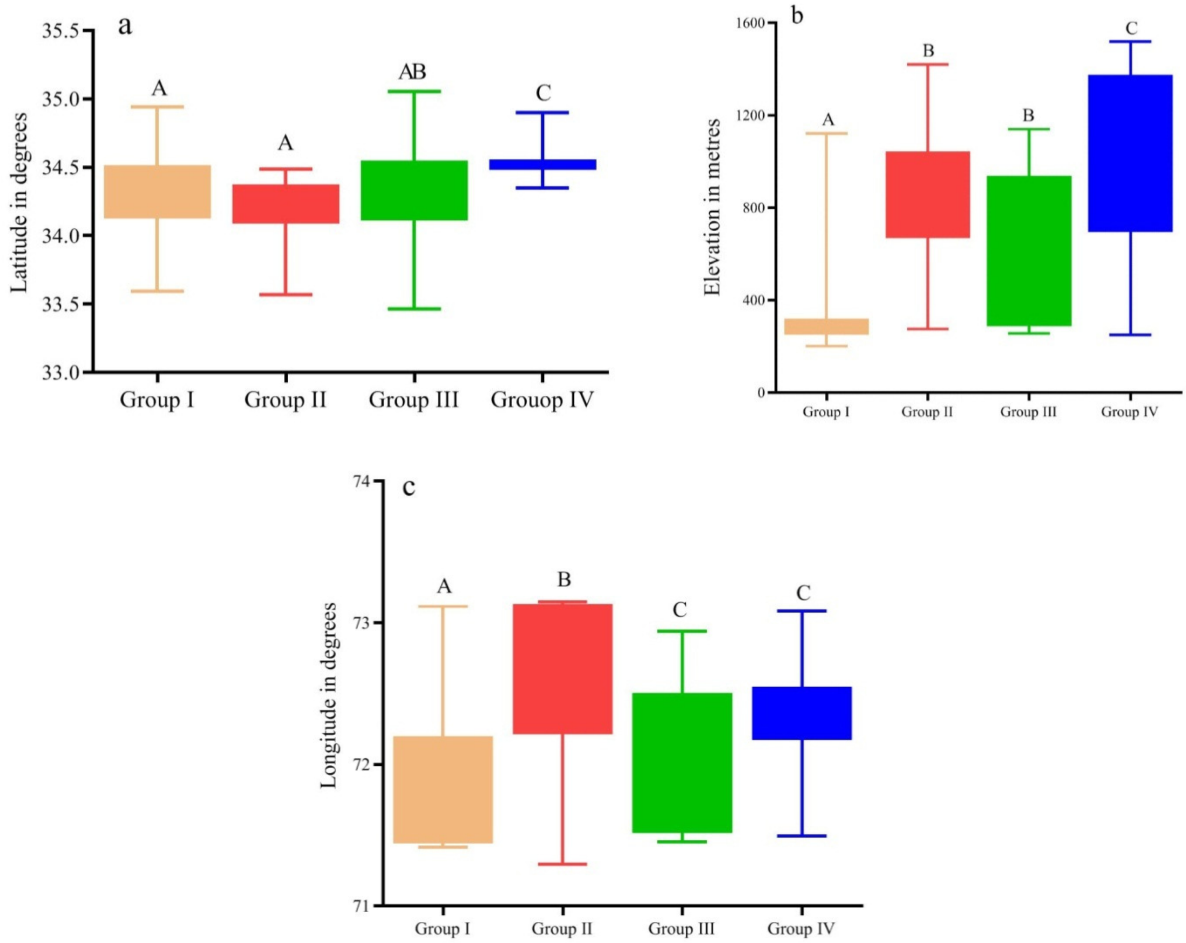

Figure 5. Box-plot diagrams for the significant indicator values (**a**) (latitude in degree: N°); (**b**) (elevation in meters from sea level); (**c**) (longitude in degree: E°); the four vegetation communities; Different capital letter indicate significant difference at $p < 0.0.5$, the details and abbreviations are given in Tables S1 and S2.

3.5. Pattern of Communities' Composition

The CCA analysis revealed 21.3% of the variance on the three axes, in which the axis contributes 8.7, followed by axis 2 and 3 (Table 4). The Eigenvalues were 0.28, 0.22 and 0.19 for the three axes.

Table 4. Summary statistics for the first three axes obtained from CCA-ordination.

Total Variance ("Inertia") in the Species Data: 3.3001	Axis 1	Axis 2	Axis 3
Eigenvalues	0.28	0.22	0.19
% of variance explained	8.7	6.8	5.9
Cumulative % explained	8.7	15.4	21.3
Pearson Correlation, Spp-Envt *	0.769	0.924	0.926
Kendall (Rank) Corr., Spp-Envt	0.453	0.697	0.762

The floristic variation in the four assemblages was predominately structured and influenced by topographic and soil gradients (Figure 6). Six indicator values of the twenty-two environmental variables investigated were found to significantly influence the vegetation and be reflected in the main ordination axes (Table 5).

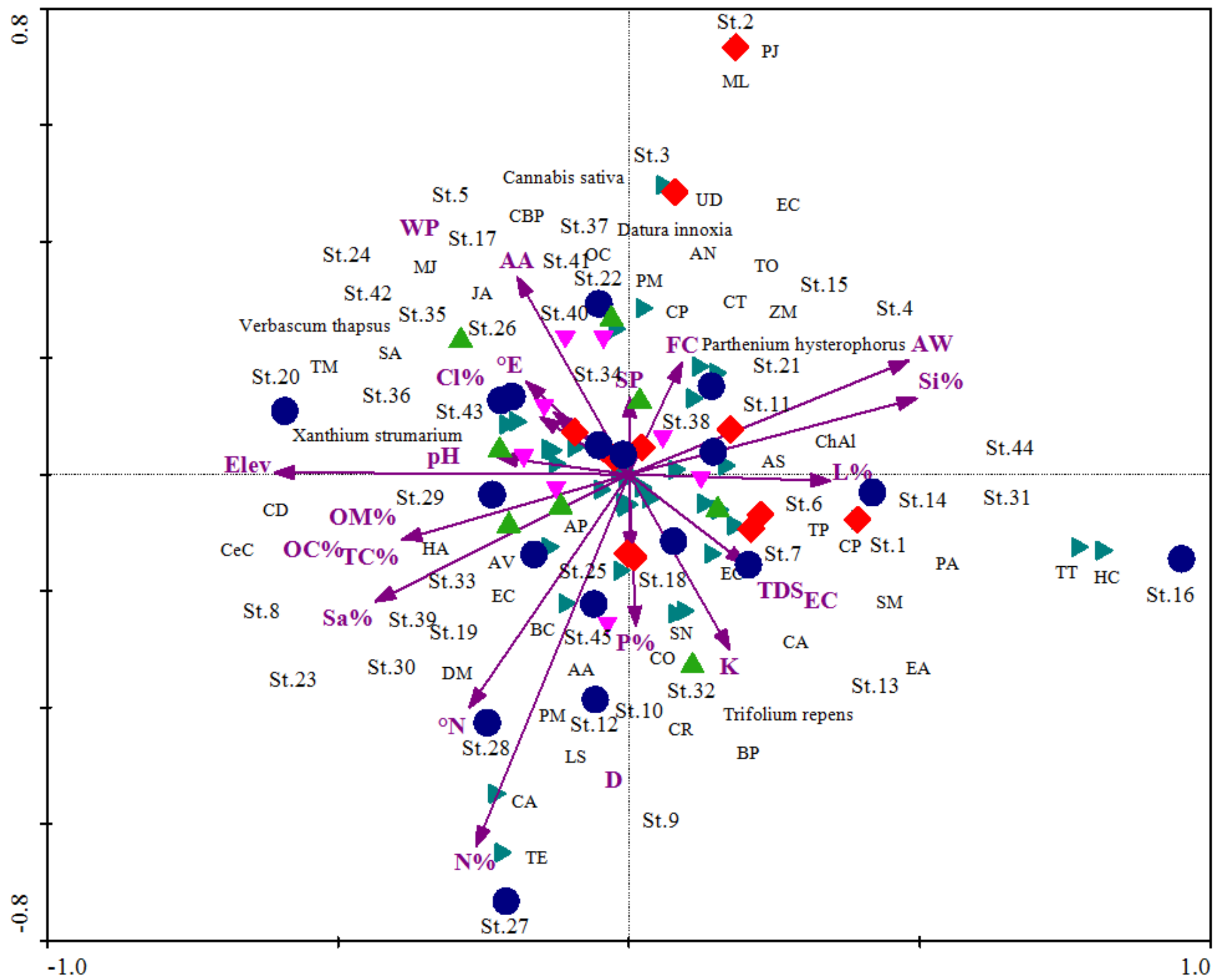

Figure 6. CCA-biplot ordinations of the 45 stands and 50 plant species associated with *X. strumarium*. Acronyms of the species and stands are presented in Table S2. Arrows indicate the vectors of significant indicator values. Elev (elevation); OM% (organic matter percentage); OC (organic carbon capacity); AW (available water) Si% (silt percentage); Sa (sand percentage) TC% (total carbon percentage) L% (Lime percentage); Species codes are the same as that mentioned in Table S2.

The first ordination axis had significant positive correlations with organic matter (r = 0.307), organic carbon (r = 0.307) and total carbon, (r = 0.307), respectively. The second axis explained 6.8% of the floristic variation and can be interpreted as an elevation gradient showing a negative effect ($r = -0.288$) on *X. strumarium*-dominated vegetation. In contrast, silt content showed a relatively weak positive relationship (r = 0.231) and potentially favored populations of this invasive species. The CCA-ordination biplot did not separate the vegetation types, with species and stands tending to be scattered, and some compactly in the center along axis 1 and 2, respectively indicating homogenization of the communities. Species such as *Trifolium repens* and *Verbascum thapsus* were located in the lower right whereas, major exotic and native invasive species such as *X. strumarium*, *C. sativa*, *P. hysterophorus* and *D. metal* were positioned in the upper left in ordination configuration (Figure 6).

Table 5. Intra-set correlations and biplot scores of the twenty-two environmental variables associated with *Xanthium* dominated communities. The first three axes of CCA ordination are computed in the analysis.

Variable	Inter-Set Correlations *			Biplot Scores		
	Axis 1	**Axis 2**	**Axis 3**	**Axis 1**	**Axis 2**	**Axis 3**
Elev	0.174	−0.609 ***	−0.339 **	0.093	−0.288 *	−0.149
N°	0.298	−0.191	0.338 **	0.159	−0.09	0.149
E°	0.119	−0.241	−0.052	0.064	−0.114	−0.023
AA	−0.039	−0.26	−0.255	−0.021	−0.123	−0.112
Cl%	0.163	−0.21	0.022	0.087	−0.099	0.01
Si%	−0.284	0.489 **	−0.056	−0.152	0.231	−0.024
Sa%	0.194	−0.386	0.045	0.104	−0.182	0.02
P1:5	−0.019	−0.218	0.084	−0.01	−0.103	0.037
OM%	0.574 ***	−0.429 **	−0.221	0.307 *	−0.203	−0.097
OC%	0.574 ***	−0.429 **	−0.221	0.307 *	−0.203	−0.097
L %	−0.273 *	0.35 **	0.359 **	−0.146	0.165	0.158
TC%	0.574 ***	−0.429 **	−0.221	0.307 *	−0.203	−0.097
N	0.367 **	−0.274 *	0.06	0.196	−0.13	0.026
P	0.114	0.051	−0.206	0.061	0.024	−0.091
K	0.032	0.201	0.337 *	0.017	0.095	0.148
EC	0.013	0.12	−0.246	0.007	0.057	−0.108
TDS	0.013	0.12	−0.246	0.007	0.057	−0.108
WP	0.155	−0.19	0.006	0.083	−0.09	0.003
FC	0.029	0.021	−0.009	0.016	0.01	−0.004
D	−0.071	0.059	−0.024	−0.038	0.028	−0.01
SP	0.07	−0.056	0.023	0.037	−0.026	0.01
AW	−0.286 *	0.459 **	−0.034	−0.153	0.217	−0.015

Note: $p < 0.001$ for ***. $p < 0.01$ for ** and $p < 0.05$ for *.

4. Discussion

4.1. Invasive Potential of X. strumarium

The exact pathway and year of *X. strumarium* invasion in the region is not known, but is reported for the first time by [33] in Pakistan and neighbouring countries. In the last two decades, *X. strumarium* has been introduced unintentionally into multiple regions of Khyber Pakhtunkhwa during the movement of Afghan refugees, and it has subsequently established, naturalized and propagated widely, with adverse effects on biodiversity and agriculture [26].

Invasive plant species introduced into new environments may either propagate or perish depending on their adaptability in new environments. It is difficult to predict whether the exotic species will establish and become naturalized in the new environment [66,67]. When successful, invasive plants often proliferate, changing vegetation composition and environmental parameters [68–70], and consequently threaten native flora and fauna [20,71]. Our study supported earlier claims that *X. strumarium* has successfully displaced native plant species and spread throughout the semi-arid regions of Pakistan to become one of the prominent invasive species in the region, and furthermore provided insight into the mechanisms that enabled this. We found that seed germination rates of this species (75%) exceed those of other invasive plants, for example those reported for *B. papyrifera* (25%) [49]. Furthermore, the results of our discriminant analysis indicated higher sexual propagation and seed and fruit formation in this species compared to other regional invasive species as reported by [9,49,65].

4.2. Local Distribution of X. strumarium

Cluster analysis identified four distinct vegetation assemblages dominated by *X. strumarium*. These communities were found to be dominated by other invasive species, either naturalized or native, including *Cannabis sativa*, *Parthenium hysterosporus* and *Acyranthus aspera*. These particular invasive species have been found to be co-dominant in other communities' according to other authors. For example, [34] reported *P. hysterosporus* growing alongside *X. strumarium* in communities in the Boren zone, Ethiopia, as did [72] in Punjab Pakistan. *Xanthium-Cannabis* communities were reported by [73] from Lucknow, India. In the present study, most of the species we found to have a strong association with *X. strumarium* L. were invasive, including *C. sativa* L., *P. hysterosporus* L. and *Datura innoxia* L. Only one species associated with it, *A. aspera* L., was non-invasive. The invasive species with which it was associated were all noxious weeds which pose high risk and threat to future biodiversity. This finding supports the hypothesis of reduction in biodiversity as a result of the arrival of invasive plants, as reported by many authors, including [74–78]. Our findings also provide further evidence for the observation that *X. strumarium-P. hysterosporus* support each other in community invasion [79], and the findings of a *X. strumarium-D. innoxia* association as reported by [80] from Soon Valley, Pakistan.

In terms of plant association, the Group II community had twenty plant species forming a species rich stand. The community was found at an elevation of 843.1 ± 70.3 m and had the highest organic matter and Nitrogen contents (1.67 ± 0.19% and 0.064 ± 0.014%, Table 3), which may be a possible reason for its diversity compared to community I, III and IV. Community IV was found to have the lowest diversity of all four communities and a high IVI for *X. strumarium* L. of 50.93 ± 3.00. This matches the information in the literature pertaining to the role of invasive plants in reducing biodiversity and leading to biotic homogenization of native plant communities [81]. Seedling establishment of *X. strumarium* is known to be promoted in native communities subject to human disturbance, a finding our study supports, and one reported for other exotic species in the region, such as *Dodonaea viscosa* in Malakand as reported by [59,82], and for *P. hysterosporus* in the same region by [65].

4.3. X. strumarium Invasion and Environmental Variables

We recorded 50 plant species in 45 different stands covering wide ecological habitats. These species belonging to 25 families, of which Astereacea, Amaranthaceae, Solanaceae, Brassicaceae and Fabaceae were species-rich families, whereas the remaining families were species poor. In addition to low species richness, this association between particular plant families and *X. strumarium* in invaded areas has been reported worldwide. For example, [34] reported that the major families of *X. strumarium*-dominated communities were *Asteraceae, Poaceae, Amaranthaceae* and *Fabaceae*, and similar findings were reported by [20,35,72]. While our results matched these findings, discrepancies in taxonomic associations at the family level may be due to geography and climate [83].

The communities were dominated by annual and perennial plant species which relate to contrasting views expressed in the literature that (1) annuals in particular have pronounced effects on community homogenization [84] and (2) perennials promote communities disturbance and thus invasion [85,86]. Compared to *X. strumarium, P. hysterosporus* and *C. sativa* are small herbs which may be at a disadvantage given the tendency for smaller herbs to be progressively replaced by larger plants [79]. We also found that the invasion of *X. strumarium* was prominent on the roads/wastes field sides in herb or shrub-dominated communities, and in agricultural fields. Similarly, [87–91] have predicted road pavements, railway tracks, and agricultural lands are most susceptible to plant invasion. Moreover, low diversity indexes were recorded which may correspond to the high invasion rate in the measured sites. Low diversity indexes in *X. strumarium*-invaded sites were also reported by [20,34,35]. Shannon-diversity and IVI indicated a decreasing trend along elevational gradients in *X. strumarium*-dominated communities. The explanation for this elevational impact is not clear since the effects of an increase in non-native plants is poorly understood on spatial and temporal scales of this sort [92].

As to the environmental influences on species invasion, we found that these may include climate and soil characteristics, similar to [93]. Soil and climate may be more important than believed and warrant further evaluation alongside the commonly implicated invasion factors of anthropogenic disturbance and propagule production [94]. In addition, road networks may be a dominant spreading factor for exotic species, particularly in highland environments [95].

Elevation is considered a predominant factor and explanatory variable in determining community structure and invasion susceptibilities. [96] were of the view that plant invasion is mainly restricted to lowland areas because climatic conditions become harsher with increasing elevation. We found that vegetation characteristics (i.e., Average Importance value percentage, Average cover, height and density) varied across elevation, indicating its prominent role. These variations occurred in conjunction with environmental variables such as latitude, longitude, Nitrogen percentage, Potassium (mg/Kg), Electrical conductivity (µs/cm), Total dissolved solids (ppm) and Lime ($CaCO_3$) percentage. In contrast, soil texture was sandy-loam or silty-loam throughout the study sites, having less or no variation in soil composition. Similar results have also been reported by [97,98] while evaluating vegetation structure and its key drivers, with differences in community composition and factors intensity attributed to differences in species identity, climate and vegetation composition among sites.

4.4. Pattern of Communities' Composition

Gradual changes in plant communities across environmental gradients are prominent and important for vegetation invaded by alien invasive species [99]. In CCA results, topographic and soil factors, i.e., elevation, soil texture, organic matter%, organic carbon%, total carbon%, Lime% and available water, are important factors that can affect *X. strumarium* communities' structure and composition. Organic matter promotes soil structure, porosity and water availability [100,101]. We found increased organic and total carbon in *X. strumarium*-dominated communities, which was significantly contributing to its invasion [80], also indicating the importance of organic matter in sustaining *Xanthium-Datura* communities. *Xanthium* species tend to grow well in marshy places, as reported by [29], suggesting that available water is a significant contributing factor in determining the growth and reproduction of the species in communities, while [102] describe the importance of water for *X. sibricum* seed germination and growth production. Elevation in inter-set correlation (Table 5) shows a significant negative correlation on axes 2 and 3, indicating the rapid spread of this plant species along altitudinal gradients. This may be due to its propagule transport by nomadic peoples and their domestic animals (sheep and goats) as they travel from the plains to the highlands during their seasonal migration. The elevation gradient brings a distinct pattern of vegetation and floristic composition due to changes in micro- and macro-climate along the gradient [103], a trend strengthened by several recent studies [59,60,104,105].

In summary, our study suggests that the focal species has wide ecological amplitude with respect to elevation. It was found throughout the area surveyed and affected the native plant populations negatively. Its pattern of expansion with respect to altitude was in accordance with other studies [36,106].

5. Conclusions

In the study, we found that the focal plant species represents a strong ruderal component in the study region. It is sensitive to elevation and produces taller, larger plants at low altitudes and even at higher altitudes at ruderal sites having a higher importance value index. The species was also found to negatively impact the diversity of communities, facilitated by effective propagation and invasive potential, a feature that relates to its high germination percentage. Additionally, phytosociological characteristics of *X. strumarium* changed across the elevation gradient, suggesting a shift in phenological, morphological, and biomass allocation that was recently reported by [107] in the invaded habitats of the same region. Given its strong invasion potential, we recommend eradicating the species through ecological management, for example, by introducing native plant crops that can compete equally with this species. Alternatively, carefully managing soil nutrients and water characteristics in cultivated fields may be necessary to prevent yield decreases if the invader cannot be eradicated and persists.

However, it is worth noting that the vigorous spread of the species in the region may have benefited economically and implications for medicinal plant markets. The plant may be efficiently utilized as biomonitoring tools, as recently reported by [108], while biomass production may be utilized for biofuel and medicinal purposes. This may warrant further exploration into its potential uses. However, its invasive behavior may offset such advantages, and this would therefore need to be considered carefully, with management plans in mind. Integrated approaches that involve awareness of the human communities may be needed, for example, through surveys of farmers in particular, and by making decisions in consultation with the governmental organizations such as regional agriculture and livestock departments, and by local non-governmental organizations as proposed by [109]. In addition, for efficient control, exploration of invasive species' morphological, phenological, phytochemical, physiological and reproductive biology assessment is required [110]. Invasion may be monitored qualitatively using species inventories (seasonally) and quantitatively using phytosociological approaches and mapping utilizing ground-based methods (through map overlays or GPS), remotely sensed pictures (aerial photos, high resolution multi-spectral digital data). Plant invasions in new places change the dynamics of indigenous communities, reduce species diversity, disrupt ecosystem processes and result in massive economic and ecological imbalances. The construction of a plant detection network in the study area and communication connections between taxonomists, ecologists and land managers are required to monitor and control invasive species. Moreover, we recommend that this invasive species' positive and negative aspects be considered in a broader, systematic framework to overcome the potential tensions between its risks and benefits, as revealed by [111].

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14127141/s1, Figure S1: Status, Habitat, Family and Native country wise distribution of plants found in association with *Xanthium strumarium* dominated communities of KP Pakistan. Table S1: Indices of phytosociological attributes for fifty plant species in the four clusters of *X. strumarium* dominated communities. Values are means (mean importance values (±SE) of the importance values obtained from the relative scores of frequency, density and cover data. The symbol (hyphen –) refer to species absent in a particular group. Table S2: Taxonomic, ecological and phyto-geographical details of plant species associated with *X. strumarium* in Khyber Pakhtunkhwa, Pakistan. Table S3: Correlation coefficients among different environmental variables influencing the distribution of *X. strumarium* in Khyber Pakhtunkhwa, Pakistan.

Author Contributions: N.K. supervised the research project. R.U. conducted the research and prepared initial draft of the manuscript. N.H. thoroughly edit and refined the manuscript and also visualized results and discussion parts. K.A. provides the basic idea and visualized the data analysis. M.E.H.K. provide valuable information about the explanation of statistical and multivariate analysis, and D.A.J. refined the data analysis and discussion of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding. A discount on APC will be applied as the authors are associated with Qatar National Library (QNL).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All the data of the manuscript is available in the manuscript tables and figure and also as Supplementary Material.

Acknowledgments: We acknowledged Shahid Shaukat who provided very valuable comments on the manuscript. Gul Rahim, curator Herbarium and Botanical Garden and Ali Hazrat, Associate Professor in the Department of Botany, University of Malakand are appreciated for their assistance in plants species identification. Ata Ur Rahman, Muhammad Uzair, Tareef Ullah and some local farmers who assisted a lot in fieldwork.

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

References

1. Fan, P.; Ouyang, Z.; Basnou, C.; Pino, J.; Park, H.; Chen, J. Nature-based solutions for urban landscapes under post-industrialization and globalization: Barcelona versus Shanghai. *Environ. Res.* **2017**, *156*, 272–283. [CrossRef]
2. Gaertner, M.; Larson, B.M.; Irlich, U.M.; Holmes, P.M.; Stafford, L.; van Wilgen, B.W.; Richardson, D.M. Managing invasive species in cities: A framework from Cape Town, South Africa. *Landsc. Urban Plan.* **2016**, *151*, 1–9. [CrossRef]
3. Gallardo, B.; Aldridge, D.C.; González-Moreno, P.; Pergl, J.; Pizarro, M.; Pyšek, P.; Vilà, M. Protected areas offer refuge from invasive species spreading under climate change. *Glob. Change Biol.* **2017**, *23*, 5331–5343. [CrossRef]
4. Levine, J.M.; Vila, M.; Antonio, C.M.D.; Dukes, J.S.; Grigulis, K.; Lavorel, S. Mechanisms underlying the impacts of exotic plant invasions. *Proc. R. Soc. London. Ser. B Biol. Sci.* **2003**, *270*, 775–781. [CrossRef]
5. Eviner, V.T.; Garbach, K.; Baty, J.H.; Hoskinson, S.A. Measuring the effects of invasive plants on ecosystem services: Challenges and prospects. *Invasive Plant Sci. Manag.* **2012**, *5*, 125–136. [CrossRef]
6. Lee, C.E. Evolutionary genetics of invasive species. *Trends Ecol. Evol.* **2002**, *17*, 386–391. [CrossRef]
7. Alpert, P. The advantages and disadvantages of being introduced. *Biol. Invasions* **2006**, *8*, 1523–1534. [CrossRef]
8. Flory, S.L.; Clay, K. Pathogen accumulation and long-term dynamics of plant invasions. *J. Ecol.* **2013**, *101*, 607–613. [CrossRef]
9. Rathee, S.; Ahmad, M.; Sharma, P.; Singh, H.P.; Batish, D.R.; Kaur, S.; Kohli, R.K. Biomass allocation and phenotypic plasticity are key elements of successful invasion of Parthenium hysterophorus at high elevation. *Environ. Exp. Bot.* **2021**, *184*, 104392. [CrossRef]
10. Tilman, D. Community invasibility, recruitment limitation, and grassland biodiversity. *Ecology* **1997**, *78*, 81–92. [CrossRef]
11. Odat, N.; Al-Khateeb, W.; Muhaidat, R.; Al-Udatt, M.; Irshiad, L. The effect of exotic Acacia saligna tree on plant biodiversity of Northern Jordan. *Int. J. Agric. Biol.* **2011**, *13*, 823–826.
12. 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] [PubMed]
13. 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 hu-man-modified ecosystems. *Proceeding R. Soc. B Biol. Sci.* **2006**, *273*, 2659–2665. [CrossRef]
14. Morri, C.; Montefalcone, M.; Gatti, G.; Vassallo, P.; Paoli, C.; Bianchi, C.N. An Alien Invader is the cause of homogenization in the recipient eco-system: A simulation-like approach. *Diversity* **2019**, *11*, 146. [CrossRef]
15. Wilson, J.R.U.; 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]
16. Begum, H.A.; Hamayun, M.; Shad, N.; Khan, W.; Ahmad, J.; Khan, M.E.H.; Jones, D.A.; Ali, K. Effects of UV radiation on germination, growth, chlorophyll content, and fresh and dry weights of *Brassica rapa* L. and *Eruca sativa* L. *Sarhad. J. Agric.* **2021**, *37*, 1016–1024. [CrossRef]
17. Thuiller, W.; Richardson, D.M.; Pyšek, P.; Midgley, G.F.; Hughes, G.O.; Rouget, M. Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale. *Glob. Change Biol.* **2005**, *11*, 2234–2250. [CrossRef]
18. Godoy, O.; Richardson, D.M.; Valladares, F.; Castro-Díez, P. Flowering phenology of invasive alien plant species compared with native species in three Mediterranean-type ecosystems. *Ann. Bot.* **2009**, *103*, 485–494. [CrossRef]
19. Dudley, S.A. Plasticity and the functional ecology of plants. In *Phenotypic Plasticity: Functional and Conceptual Approaches*; Oxford University Press: Oxford, UK, 2004; p. 2.
20. Qureshi, H.; Anwar, T.; Arshad, M.; Osunkoya, O.O.; Adkins, S.W. Impacts of *Xanthium strumarium* L. Invasion on vascular plant diversity in Pothwar region (Pakistan). *Ann. Bot.* **2019**, *9*, 73–82.
21. Khan, S.M.; Page, S.; Ahmad, H.; Harper, D. Ethno-ecological importance of plant biodiversity in mountain ecosystems with special emphasis on indicator species of a Himalayan Valley in the northern Pakistan. *Ecol. Indic.* **2014**, *37*, 175–185. [CrossRef]
22. Khan, K.; Ullah, S.; Ullah, A.; Khan, S.; Saragih, M.Y. Impact of Farmforestry on Socio-Economic Condition of Farming Communities in District Mardan, Pakistan. *Bp. Int. Res. Crit. Inst. BIRCI-J. Humanit. Soc. Sci.* **2020**, *3*, 2649–2661.
23. Hussain, A.; Zarif, R.M. Invasive alien tree species—A threat to biodiversity. *Pak. J. For.* **2003**, *53*, 127–141.
24. Shinwari, M.I.; Shinwari, M.I. Botanical diversity in Pakistan; past present and future. *World Environ.* **2010**, *1*, 85–104.
25. Hussain, A. Pakistan. In *Invasive Alien Species in South-Southeast Asia: National Reports and Directory of Resources*; Pallewatta, N., Reaser, J.K., Gutierrez, A.T., Eds.; Global Invasive Species Programme: Cape Town, South Africa, 2003; pp. 70–79.
26. Marwat, K.B.; Hashim, S.; Ali, H. Weed Management: A case study from North-West Pakistan. *Pak. J. Bot.* **2010**, *42*, 341–353.
27. Alex, J. Development of weed problems in Canada. *Biol. Ecol. Weeds* **2013**, *2*, 309.
28. Holm, L.G.; Plunknett, D.L.; Pancho, J.V.; Herberger, J.P. *The World's Worst Weeds*; East-West Center Book Univeristy Press of Hawaii: Honolulu, HI, USA, 1977; p. 609.
29. Love., D.; Dansereau, P. Biosystematic studies on *Xanthium*: Taxonomrc appraisal and ecological status. *Can. J. Bot.* **1959**, *37*, 173–208. [CrossRef]
30. Hashim, S.; Marwat, K.B.; Saeed, M.; Haroon, M.; Waqas, M.; Shah, F. Developing a sustainable and ecofriendly weed management system using organic and inorganic mulching techniques. *Pak. J. Bot.* **2013**, *45*, 483–486.
31. Hussain, Z.; Marwat, K.B.; Cardina, J.; Khan, I.A. *Xanthium strumarium* L. impact on corn yield and yield components. *Turk. J. Agric. For.* **2014**, *38*, 39–46. [CrossRef]

32. Qureshi, H.; Arshad, M.; Bibi, Y. Invasive flora of Pakistan: A critical analysis. *Int. J. Biosci.* **2014**, *4*, 407–424.
33. Baloch, G.M.; Mohyuddin, A.I.; Ghani, M.A. *Xanthium stmmarium* L.-insects and other organisms associated with it in West Pakistan. *Tech. Bull. Commonw. Inst. Biol. Control.* **1968**, *10*, 103–111.
34. Seifu, A.; Seboka, N.; Misganaw, M.; Bekele, T.; Merawi, E. Impact of Invasive Alien Plant, *Xanthium Strumarium*, On Species Diversity and Composition of Invaded Plant Communities in Borena Zone, Ethiopia. *Biodivers. Int. J.* **2017**, *1*, 4. [CrossRef]
35. Iqbal, M.; Iram, A.; Liu, M.C.; Feng, Y.L. Competitive approach of invasive cocklebur (*Xanthium strumarium*) with native weed species diversity in Northeast China. *BioRxiv* **2020**. [CrossRef]
36. Tadesse, N.S.; Assefa, A.S.; Motbaynor, M.M.; Betsiha, E.M.; Hailu, A.A.; Beyene, G.F.; Hordofa, T.B. Invasion and impacts of *Xanthium strumarium* in Borena Zone of Oromia Region, Ethiopia. *J. Coast. Life Med.* **2017**, *5*, 350–355. [CrossRef]
37. Ahmad, D. *Khyber Pakhtunkhwa State of the Environment*; Environmental Protection Agency, Government of Khyber Pakhtunkhwa: Peshawar, Pakistan, 2012.
38. Ali, A.; Khan, T.A.; Ahmad, A. Analysis of Climate Data of Khyber Pakhtunkhwa, Pakistan. *Int. Res. J. Eng. Technol.* **2018**, *5*, 4266–4283. [CrossRef]
39. FAO. Land Cover Atlas of Pakistan. In *The Khyber Pakhtunkhwa Province and Federally Administered Tribal Areas*; A joint publication by FAO, SUPARCO and Crop Reporting Service; Government of KP and FATA: Peshawar, Pakistan, 2016.
40. Malkani, M.S.; Khosa, M.H.; Alyani, M.I.; Khan, K.; Somro, N.; Zafar, T.; Zahid, M.A. Mineral Deposits of Khyber Pakhtunkhwa and FATA, Pakistan. *Lasbela Univ. J. Sci. Technol.* **2017**, *6*, 23–46.
41. Stewart, R.R. *Annotated Catalogue of Vascular plants of West Pakistan and Kashmir*; Fakhri Printing Press: Karachi, Pakistan, 1972; pp. 1–1027.
42. Ahmad, H.; Khan, B. *Environmental Profile of NWFP*, 2nd ed.; Environmental Protection Agency: Peshawar, Pakistan, 2016.
43. Rejmanek, M.; Richardson, D.M. What attributes make some plant species more invasive? *Ecology* **1996**, *77*, 1655–1661. [CrossRef]
44. Morsdorf, F.; Mårell, A.; Koetz, B.; Cassagne, N.; Pimont, F.; Rigolot, E.; Allgöwer, B. Discrimination of vegetation strata in a multi-layered Mediterranean forest ecosystem using height and intensity information derived from airborne laser scanning. *Remote Sens. Environ.* **2010**, *114*, 1403–1415. [CrossRef]
45. Curtis, J.T.; McIntosh, R.P. The interrelations of certain analytic and synthetic phytosociological characters. *Ecology* **1950**, *31*, 434–455. [CrossRef]
46. Martínez-Falcón, A.P.; Zurita, G.A.; Ortega-Martínez, I.J.; Moreno, C.E. Populations and assemblages living on the edge: Dung beetles responses to forests-pasture ecotones. *PeerJ* **2018**, *6*, e6148. [CrossRef]
47. Nasir, E.; Ali, S.I. (Eds.) *Flora of West Pakistan*; Fakhri Press: Karachi, Pakistan, 1972.
48. Aeschimann, D.; Lauber, K.; Moser, D.M.; Theurillat, J.P. *Flora Alpina*; Belin: Paris, France, 2004.
49. Maan, I.; Kaur, A.; Singh, H.P.; Batish, D.R.; Kohli, R.K. Exotic avenue plantations turning foe: Invasive potential, distribution and impact of Broussonetia papyrifera in Chandigarh, India. *Urban For. Urban Green.* **2021**, *59*, 127010. [CrossRef]
50. Castillón, E.E.; Arévalo, J.R.; Quintanilla, J.Á.V.; Rodríguez, M.M.S.; Encina-Domínguez, J.A.; Rodríguez, H.G.; Ayala, C.M.C. Classification and ordination of main plant communities along an altitudinal gradient in the arid and temperate climates of northeastern Mexico. *Sci. Nat.* **2015**, *102*, 59. [CrossRef]
51. Kamrani, A.; Jalili, A.; Naqinezhad, A.; Attar, F.; Maassoumi, A.A.; Shaw, S.C. Relationships between environmental variables and vegetation across mountain wetland sites, N. Iran. *Biologia* **2011**, *66*, 76–87. [CrossRef]
52. Reis, A.T.; Coelho, J.P.; Rucandio, I.; Davidson, C.M.; Duarte, A.C.; Pereira, E. Thermo-desorption: A valid tool for mercury speciation in soils and sediments? *Geoderma* **2015**, *237*, 98–104. [CrossRef]
53. Nelson, D.W.; Sommers, L.E. Total carbon, organic carbon, and organic matter. In *Methods of Soil Analysis: Part 3 Chemical Methods*; American Society of Agronomy, Crop Science Society of America, Soil Science Society of America: Madison, WI, USA, 1996; Volume 5, pp. 961–1010.
54. Yadav, R.L.; Tomar, S.S.; Sharma, U.C. Output: Input ratios and apparent balances of N, P and K inputs in a rice-wheat system in North-West India. *Exp. Agric.* **2002**, *38*, 457–468. [CrossRef]
55. Arend, M.; Gessler, A.; Schaub, M. The influence of the soil on spring and autumn phenology in European beech. *Tree Physiol.* **2016**, *36*, 78–85. [CrossRef]
56. Gangwar, D.P.; Baskar, M. *Texture Determination of Soil by Hydrometer Method for Forensic Purpose*; Central Forensic Science Laboratory: Chandigarh, India, 2019.
57. Hailu, H. Analysis of vegetation phytosociological characteristics and soil physicochemical conditions in Harishin Rangelands of Eastern Ethiopia. *Land* **2017**, *6*, 4. [CrossRef]
58. McCune, B. Influence of noisy environmental data on canonical correspondence analysis. *Ecology* **1997**, *78*, 2617–2623. [CrossRef]
59. Khan, N.; Shaukat, S.S.; Ahmad, M.; Siddiqui, M.F. Vegetation-environment relationships in the forests of Chitral District Hindukush range of Pakistan. *J. For. Res.* **2013**, *24*, 205–216. [CrossRef]
60. Khan, N.; Ali, F.; Ali, K.; Shaukat, S. Composition, structure and regeneration dynamcis of *Olea ferruginea* Royle forests from Hindikush ranges of Pakistan. *J. Mt. Sci.* **2015**, *12*, 647–658.
61. Biondi, E.; Allegrezza, M.; Casavecchia, S.; Galdenzi, D.; Gasparri, R.; Pesaresi, S.; Blasi, C. New insight on Mediterranean and sub-Mediterranean syntaxa included in the Vegetation Prodrome of Italy. *Flora Mediterr.* **2015**, *25*, 77–102.
62. Rahman, H.U.; Nabi, G.; Ali, I.; Tahir, T.; Ahmed, M. Growth and yield of Kinnown (*Citrus reticulata Blanco*) and soil physical properties as affected by orchard floor management practices in Punjab, Pakistan. *Soil Environ.* **2012**, *31*, 163–170.

63. Barua, N.; Aziz, M.A.I.; Tareq, A.M.; Sayeed, M.A.; Alam, N.; ul Alam, N.; Emran, T.B. In vivo and in vitro evaluation of pharmacological activities of *Adenia trilobata* (Roxb.). *Biochem. Biophys. Rep.* **2020**, *23*, 100772. [CrossRef]
64. Irshad, M.; Khan, N.; Ali, K.; Muhammad, Z. The influence of environmental variables on *Punica granatum* L. assemblages in subtropical dry temperate woodland in the district of Lower Dir, Khyber Pakhtunkhwa, Pakistan. *Turk. J. Bot.* **2016**, *40*, 610–622. [CrossRef]
65. 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]
66. Sherley, G. *Invasive Species in the Pacific*; South Pacific Regional Environment Programme: Apia, Samoa, 2000.
67. Gallien, L.; Carboni, M. The community ecology of invasive species: Where are we and what's next? *Ecography* **2017**, *40*, 335–352. [CrossRef]
68. Simon, N. *The Guiness Guide to Nature in Danger*; Guiness Publishing Ltd.: London, UK, 1993.
69. Le Maitre, D.C.; Gaertner, M.; Marchante, E.; Ens, E.J.; Holmes, P.M.; Pauchard, A.; Richardson, D.M. Impacts of invasive Australian acacias: Implications for management and restoration. *Divers. Distrib.* **2011**, *17*, 1015–1029. [CrossRef]
70. Ratnayake, R.M.C.S. Why plant species become invasive? In Proceedings of the National Symposium on Invasive Alien Species (IAS), Colombo, Sri Lanka, 27 November 2014; Volume 1.
71. Zimmermann, H.G. Biological control of mesquite, Prosopis spp. (Fabaceae), in SouthAfrica. *Agric. Ecosyst. Environ.* **1991**, *37*, 175–186. [CrossRef]
72. Iqbal, M.F.; Feng, Y.L.; Feng, W.W.; Liu, M.C.; Lu, X.R. Ecological impacts of the invasive plant *Xanthium strumarium* and the impacts of three aboveground herbivores on the invader. *Ecol. Indic.* **2021**, *131*, 108140. [CrossRef]
73. Awasthi, S.; Gupta, S.; Maurya, N.; Tripathi, P.; Dixit, P.; Sharma, N. Environmental risk factors for persistent asthma in Lucknow. *Indian J. Pediatrics* **2012**, *79*, 1311–1317. [CrossRef]
74. Gaertner, M.; Den Breeyen, A.; Hui, C.; Richardson, D.M. Impacts of alien plant invasions on species richness in Mediterranean-type ecosystems: A meta-analysis. *Prog. Phys. Geogr.* **2009**, *33*, 319–338. [CrossRef]
75. Pejchar, L.; Mooney, H.A. Invasive species, ecosystem services and human well-being. *Trends Ecol. Evol.* **2009**, *24*, 497–504. [CrossRef] [PubMed]
76. Kueffer, C. Plant invasions in the Anthropocene. *Sciecne* **2017**, *358*, 724–725. [CrossRef]
77. Jones, B.A. Tree shade, temperature, and human health: Evidence from invasive species-induced deforestation. *Ecol. Econ.* **2019**, *156*, 12–23. [CrossRef]
78. Bartz, R.; Kowarik, I. Assessing the environmental impacts of invasive alien plants: A review of assessment approaches. *NeoBiota* **2019**, *43*, 69–99. [CrossRef]
79. Timsina, B.; Shrestha, B.B.; Rokaya, M.B.; Münzbergová, Z. Impact of *Parthenium hysterophorus* L. invasion on plant species composition and soil properties of grassland communities in Nepal. *Flora-Morphol. Distrib. Funct. Ecol. Plants* **2011**, *206*, 233–240. [CrossRef]
80. Zia, A.; Ahmad, S.S.; Bashir, H. Assessment of Vegetation-Edaphic Correlation of Wetland Complex of Soon Valley, Pakistan using Multivariate Techniques. *Biol. Sci. PJSIR* **2018**, *61*, 21–31. [CrossRef]
81. Blackburn, T.M.; Py_sek, P.; Bacher, S.; Carlton, J.T.; Duncan, R.P.; Jaro_s_ık, V.; Wilson, J.R.U.; Richardson, D.M. A proposed unified framework for biological invasions. *Trends Ecol. Evol.* **2011**, *26*, 333–339. [CrossRef]
82. Bekele, T. Plant Population Dynamics of *Dodonaea angustifolia* and *Olea europaea* ssp. Cuspidata in Dry Afromontane Forests of Ethiopia. Ph.D. Thesis, Uppsala University, Uppsala, Sweden, 2000.
83. Kosanic, A.; Anderson, K.; Harrison, S.; Turkington, T.; Bennie, J. Changes in the geographical distribution of plant species and climatic variables on the West Cornwall peninsula (South West UK). *PLoS ONE* **2018**, *13*, e0191021. [CrossRef]
84. 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]
85. 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]
86. 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]
87. Salgado, J.; Vélez, M.I.; Caceres-Torres, L.C.; Villegas-Ibagon, J.A.; Bernal-Gonzalez, L.C.; Lopera-Congote, L.; González-Arango, C. Long-term habitat degradation drives neotropical macrophyte species loss while assisting the spread of invasive plant species. *Front. Ecol. Evol.* **2019**, *7*, 140. [CrossRef]
88. Davies, K.W.; Nafus, A.M.; Madsen, M.D. Medusahead invasion along unimproved roads, animal trails, and random transects. *West. North Am. Nat.* **2013**, *73*, 54–59. [CrossRef]
89. Brisson, J.; de Blois, S.; Lavoie, C. Roadside as invasion pathway for common reed (*Phragmites australis*). *Invasive Plant Sci. Manag.* **2010**, *3*, 506–514. [CrossRef]
90. Richardson, D.M. Invasion science: The roads travelled and the roads ahead. In *Fifty Years of Invasion Ecology: The Legacy of Charles Elton*; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2011; pp. 397–401.
91. Burleigh, B.A. Host cell signaling and Trypanosoma cruzi invasion: Do all roads lead to lysosomes? *Sci. STKE* **2005**, *2005*, pe36. [CrossRef] [PubMed]

92. Dietz, H.; Edwards, P.J. Recognition that causal processes change during plant invasions helps explain conflicts in evidence. *Ecology* **2006**, *87*, 1359–1367. [CrossRef] [PubMed]
93. Barni, E.; Bacaro, G.; Falzoi, S.; Spanna, F.; Siniscalco, C. Establishing climatic constraints shaping the distribution of alien plant species along the elevation gradient in the Alps. *Plant Ecol.* **2012**, *213*, 757–767. [CrossRef]
94. Mack, R.N.; Simberloff, D.; Lonsdale, W.M.; Evans, H.; Clout, M.; Bazzaz, F.A. Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecol. Appl.* **2000**, *10*, 689–710. [CrossRef]
95. Haider, S.; Alexander, J.; Dietz, H.; Trepl, L.; Edwards, P.J.; Kueffer, C. The role of bio-climatic origin, residence time and habitat context in shaping non-native plant distributions along an altitudinal gradient. *Biol. Invasions* **2010**, *12*, 4003–4018. [CrossRef]
96. Nievas, R.P.; Calderon, M.R.; Moglia, M.M. Environmental factors affecting the success of exotic plant invasion in a wildland-urban ecotone in temperate South America. *Neotrop. Biol. Conserv.* **2019**, *14*, 257. [CrossRef]
97. Pauchard, A.; Alaback, P. La amenaza de plantas invasoras. *Chile For.* **2002**, *289*, 13–15.
98. Koutika, L.S.; Vanderhoeven, S.; Chapuis-Lardy, L.; Dassonville, N.; Meerts, P. Assessment of changes in soil organic matter after invasion by exotic plant species. *Biol. Fertil. Soils* **2007**, *44*, 331–341. [CrossRef]
99. Setälä, H.M.; Francini, G.; Allen, J.A.; Hui, N.; Jumpponen, A.; Kotze, D.J. Vegetation type and age drive changes in soil properties, nitrogen, and carbon sequestration in urban parks under cold climate. *Front. Ecol. Evol.* **2016**, *4*, 93. [CrossRef]
100. El-Bana, M.I.; Al-Mathnani, A.S. Vegetation-soil relationships in the Wadi Al-Hayat Area of the Libyan Sahara. *Australian J. Basic Appl. Sci.* **2009**, *3*, 740–747.
101. Rezaei, S.A.; Gilkes, R.J.; Andrews, S.S. A minimum data set for assessing soil quality in rangelands. *Geoderma* **2006**, *136*, 229–234. [CrossRef]
102. Liu, J.; Lin, F.; Shi, S.; Ayi, Q.; Liu, S.; Zeng, B. Effects of water level regulation on the seed germination and production of annual plant *Xanthium sibiricum* in the water-level-fluctuating-zone of Three Gorges Reservoir. *Sci. Rep.* **2017**, *7*, 5056. [CrossRef]
103. Champion, G.H.; Seth, S.K.; Khattak, G.M. *Forest Types of Pakistan*; Pakistan Forest Institute Peshawar Pakistan: Peshawar, Pakistan, 1965; p. 238. Available online: https://www.cabdirect.org/cabdirect/abstract/19950609490 (accessed on 21 October 2021).
104. Khan, N.; Ahmad, M.; Shaukat, S.; Wahab, M.; Siddiqui, M.F. Structure, diversity, and regeneration potential of *Monothheca Buxifolia* (Falc.) A. DC. Dominated forest of Lower Dir District, Pakistan. *Front. Agric. China* **2011**, *5*, 106–121. [CrossRef]
105. Haq, S.M.; Malik, A.H.; Khuroo, A.A.; Rashid, I. Floristic composition and biological spectrum of Keran-a remote valley of northwestern Himalaya. *Acta Ecol. Sin.* **2019**, *39*, 372–379. [CrossRef]
106. Ullmann, I.; Heindl, B. Geographical and ecological differentiation of roadside vegetation in temperate Europe. *Bot. Acta.* **1989**, *102*, 261–269. [CrossRef]
107. Ullah, R.; Khan, N.; Ali, K. Which factor explains the life-history of *Xanthium strumarium* L., an aggressive alien invasive plant species, along its altitudinal gradient? *Plant Direct* **2022**, *6*, e375. [CrossRef]
108. Ullah, R.; Khan, N. *Xanthium strumarium* L. an Alien Invasive Species in Khyber Pakhtunkhwa (Pakistan): A Tool for Biomonitoring and Environmental Risk Assessment of Heavy Metal Pollutants. *Arab. J. Sci. Eng.* **2021**, *47*, 255–267. [CrossRef]
109. Kapler, E.J.; Thompson, J.R.; Widrlechner, M.P. Assessing stakeholder perspectives on invasive plants to inform risk analysis. *Invasive Plant Sci. Manag.* **2012**, *5*, 194–208. [CrossRef]
110. Raghubanshi, A.S.; Rai, L.C.; Gaur, J.P.; Singh, J.S. Invasive Alien species and biodiversity in India. *Curr. Sci.* **2005**, *88*, 539–540.
111. Dickie, I.A.; Bennett, B.M.; Burrows, L.E.; Nuñez, M.A.; Peltzer, D.A.; Porté, A.; Richardson, D.M.; Rejmánek, M.; Rundel, P.W.; van Wilgen, B.W. Conflicting values: Ecosystem services and invasive tree management. *Biol. Invasions* **2014**, *16*, 705–719. [CrossRef]