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Vegetation Analysis in the Archaeological Area of Pasargadae WHS (Iran) Enhancing the Naturalistic Value of the Site within the Occurring Environmental Changes

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Abstract: This study provides pioneering research on the vegetation of archaeological areas in Iran to enhance its naturalistic and bioindication values by selecting the Pasargadae World Heritage Site (WHS). Vegetation surveys were carried out in different homogeneous habitats, analyzing the plant communities through statistical elaboration, syntaxonomic role, mapping, and enhancement of plants with conservation interest. In an ecological approach, the study included an analysis of the recent climate changes and human interventions influencing the water resources. Results revealed seven main vegetation types reflecting ecological gradients shaped by environmental, edaphic, and anthropogenic factors. The syntaxonomic analysis showed a primary subdivision in semi-natural grasslands and synanthropic vegetation. Several key species were identified as bioindicators of multiple factors, such as: *Launaea acanthodes*, *Stipa barbata*, *Alhagi maurorum*, *Bellevalia saviczii*, *Glycyrrhiza glabra*, *Convolvulus arvensis*, and *Hordeum murinum*. The vegetation map showed how the hilly grassland communities hosted the highest number of species with conservation interest and their need to be better protected. Bio-climatic data, such as the construction of dams and the exploitation for irrigation purposes, pointed to the increasing xeric conditions, which make urging conservation efforts for the site's historical and naturalistic values. The study underscores the importance of preserving places with high plant diversity for effective site management, and enhances the intricate relationship between vegetation and natural features in the occurring environmental changes.

Keywords: archaeological site; biodiversity; climate change; syntaxonomy; vegetation mapping; nature conservation

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1. Introduction

Archaeological sites display the interaction of the natural environment and human activities [1–6]. In this interaction, multiple dynamics are involved, in which vegetation can have both a negative and sometimes a positive action in the conservation of archaeological structures [7]. Indeed, the growth of plants in archaeological areas recurrently gives rise to biodeterioration phenomena, which is related to the development of their roots [8–17]. However, less consideration has been given to the benefits and values that the plants can provide, both in terms of the direct benefits they offer and the indirect advantages gained from understanding their role. In fact, the presence of plants in archaeological areas has a mitigating effect on the microclimate, thus ensuring higher stability and durability of the monuments and offering better comfort for those who visit these places [18,19]. Indeed, several studies demonstrated the mitigating action of plants by reducing solar radiation, maintaining a higher relative humidity, and reducing weathering, contaminant deposition, and wind erosion as well [20–23]. Moreover, some contributions [18,24–26] provided a methodological framework for evaluating the heritage value of vegetation. Furthermore, wild plants can also show indications of buried archaeological structures, thus adding information to the history of the site [27–31].

In addition, archaeological areas, being better protected from anthropogenic disturbance compared to other human-managed areas, have proven to be valuable refuges for biodiversity conservation [5,6,32,33]. The permanence of natural habitats and the floristic richness found in these areas is considerable, with the occurrence of a high number of species of conservation interest [6,32,34–37].

Analyzing plant communities in archaeological areas, such as their distribution and bioindication values, can greatly enhance the efficiency of site management and enrichment activities [18,20]. In fact, understanding how plant species are spatially and numerically distributed within the archaeological areas can facilitate management planning and activities, minimizing their negative impacts and promoting the benefits that plant communities can provide in these contexts [11,38,39]. Conversely, the vegetation growing on archaeological sites is influenced not only by human activities, but also by environmental and climatic conditions, as well as their ecological characteristics can serve as a bioindicator of these changes [40,41]. Due to severe climatic conditions, vegetation in arid or semi-arid environments shows a relative adaptive capacity, which becomes more significant considering current climate changes [42,43]. Vegetation maps of archaeological sites are useful tools for management planning, providing insight into the reading of the site characteristics, both for precise location of the various types of plant communities and contribution to the conservation of monuments [39].

In the Mediterranean areas, while several studies have addressed the vegetation of archaeological areas, research carried out on archaeological sites in arid or semi-arid environments is limited [6,32,44], despite their relevance and fragility caused by the occurring climatic changes. Notably, the UNESCO World Heritage Site (WHS) of Pasargadae, dating back to the 6th century BC [45,46], is of significant historical importance for its age, and its value since it is the place where the Persian Garden originated. The origin of the garden itself can be related to the favorable rainfall and hydrological conditions, since in the past the site had a high availability of water. However, the aridity has increased over the centuries, and this phenomenon has evidently intensified more recently. The present desiccation of the river was the consequence of both direct human interventions and the current climate change [47,48]. Moreover, Pasargadae is located in the border zone of the Zagros mountains, and the Irano-Turanian region, and it results in a rich ecotone from a biodiversity point of view, as well as a high naturalistic interest [6]. Following our recent floristic assessment [6] and the biodeterioration evaluation due to plant growth [17,49], we wish to deepen the knowledge of the site, by adding detailed insights into the vegetation's naturalistic values that characterize the various parts of the site and the emerging issues linked to the climatic changes. In particular, this study will analyze the different types of vegetation growing in the archaeological area to: (1) assess their ecological and syntaxonomic characteristics and enhance their bioindication values; (2) evaluate the naturalistic interest and the distribution in the area through their mapping; and (3) give a preliminary assessment of the effects of the increasing stresses induced by the warming and desiccation of the area.

The findings will be useful for both the enhancement of natural values and the protection of monuments on the site, thus ensuring a balance between the need to preserve natural and cultural values, which is an aspect that should be better considered in the management plan of archeological sites [5,10,24,39,49,50].

2. Materials and Methods

2.1. The Study Area: Pasargadae World Heritage Site

The Pasargadae Plain (Figure 1), also known as the Morghab Plain, is one of the vast alluvial sedimentary intermountain basins that is characteristic of the central and eastern part of the Zagros Mountains range [48] which form a plateau at 1400–1800 m above sea level, surrounded by a 2200–2500 m high mountain range [51]. It was formed during the Zagros orogeny, dating back to the Mesozoic era [52], and it is located in a unique position in High Zagros, where it experienced Wurm glaciation and later pluvial stages [51].

Polvar/Sivand River, the principal watercourse of Pasargadae, crosses the region from northeast to southwest, joining the plain of Persepolis downstream [48].

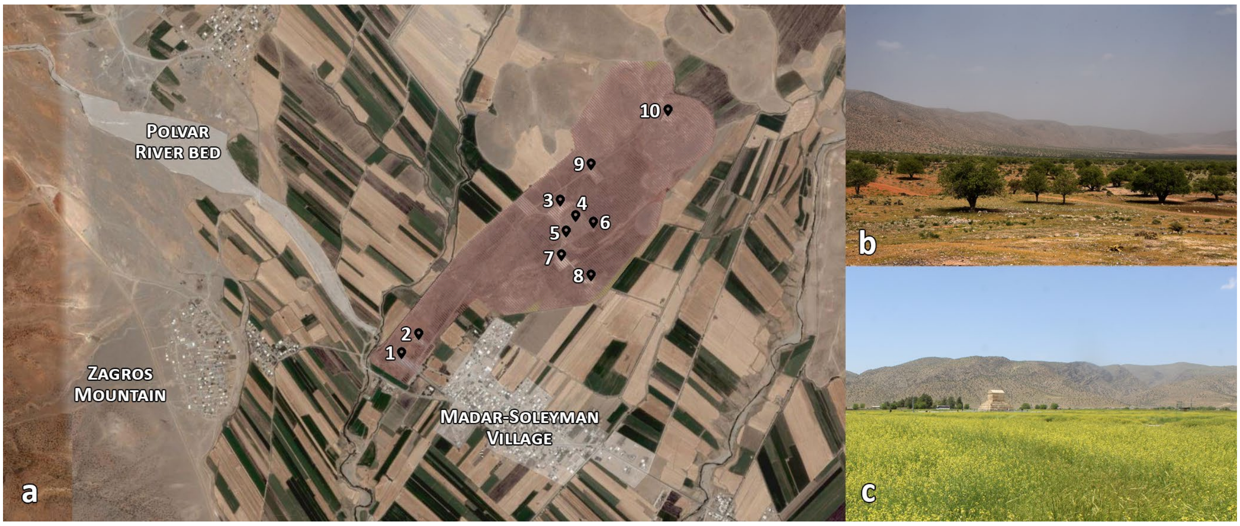

Figure 1. Views of the Pasargadae archaeological area: (**a**) the areal map of the site with the location of monuments in the site, riverbeds, Zagros Mountain, farmlands, and villages; 1. Cyrus the Great Tomb, 2. Caravanserai, 3. Private Palace, 4. Watercourses of Royal Garden, 5. Pavilion B, 6. Pavilion A, 7. Audience Hall, 8. Gate Palace, 9. Stone Tower, 10. Fortification terrace.; (**b**) the landscape of the surrounding area with trees of *Pistacia atlantica* (Babak Sedighi: archive of Pasargadae research center); and (**c**) the landscape of the Cyrus Tomb (Author, May 2019).

Pasargadae holds significant historical and geographical importance in the Fars Province of Iran since it was the location of the first capital of the Achaemenid Empire, the ancient Persian capital founded by Cyrus the Great around 546 BCE, due to the favorable orographic and hydrogeological conditions [45,46]. In fact, the plain is surrounded by a range of hills and mountains radiating from the Zagros Mountains chains, and the conditions of a well-watered basis and a wide area of arable land played an important role in the site's choice and provided a favorable environment for agricultural development [48,53]. The natural landscape of the area not only consists of Zagros and Irano-Turanian biodiversity but has also been impacted by human activities such as agriculture and pastoral activities over centuries. The plain features archaeological remains, notably the tomb of Cyrus the Great, along with other structures showcasing ancient Persian architecture and cultural achievements.

The climate of the Pasargadae area is classified within the Mediterranean xeric continental bioclimate, characteristic of southern Iran and northern Fars [54], which exhibits semi-arid features, including warm and dry summers and relatively cold winters.

Previous elaborations (2006–2021) [6] showed a certain variation in rainfall with average values of approximately only 222.8 mm, primarily concentrated from December to May, including occasional snow at higher altitudes, followed by a dry period from June to September. At the same time, the annual temperature typically ranged between 14.7–17.5 °C, with the lowest absolute temperature recorded at −10.6 °C in February and the highest at 44.4 °C in July. Relative humidity averaged around 39–41%, showcasing significant fluctuations throughout the day, with winter temperatures often falling below 0 °C [47].

2.2. Methodology

2.2.1. Vegetation Sampling

Following the phytosociological approach of the Zurich–Montpellier school [55], the vegetation survey was conducted (May 2022) in sampling areas selected on the basis of homogeneous edaphic and stational conditions in order to avoid ecotones and overlapping among different communities. In total, 33 plots of 10 m × 10 m (Figure 2) were carried out randomly in the different areas, such as highly disturbed areas near the monuments, dry riverbed areas, remnants of the Royal Garden watercourses, semi-natural grasslands, shrublands under several edaphic conditions, and stony and rocky hills. In each plot, the vegetation survey was carried out visually estimating the plant coverage index of the Braun-Blanquet scale: + = <1%; 1 = 1–5%; 2 = 5–25%; 3 = 25–50%; 4 = 50–75%; 5 = 75–100%. In addition, the most relevant environmental variables and edaphic factors, such as slope, aspect, altitude, and soil characteristics, were collected.

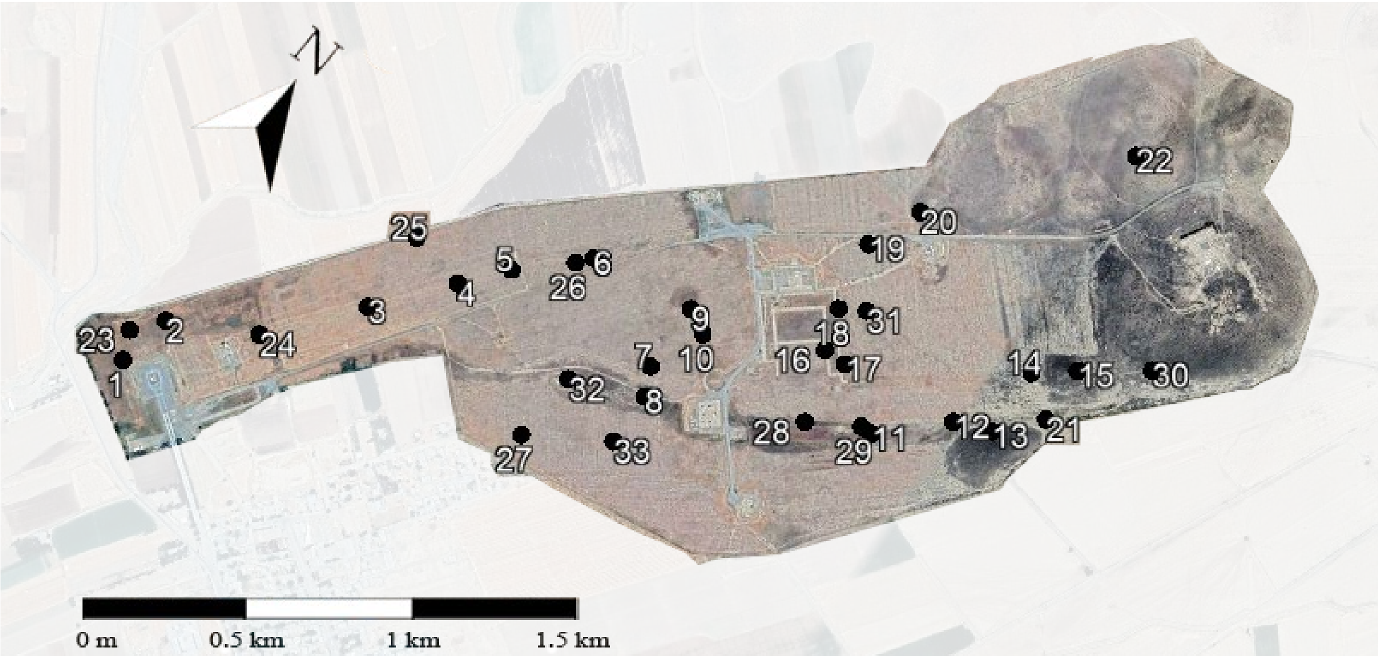

Figure 2. WHS of Pasargadae, Fars Province (Iran): map of the 33 surveys carried out within the site. The sampling locations covered: highly disturbed areas near the monuments (1–3,23,25), dry riverbed area (11,12,14,29,32), remnants of the Royal Garden watercourses (16–18), semi-natural grasslands and shrublands under several edaphic conditions (4–7,10,24,26,28,31,33), and stony and rocky hills (8,9,13,15,19–22,27,30).

For the vascular plant species identification, we used the Flora Iranica [56], comparing data with those obtained from the floristic study of Hosseini et al. [6] and with the herbarium specimens stored in the Herbarium of the University of Roma Tre. The nomenclature followed the "World of Flora Online" [57].

2.2.2. Statistical Elaborations and Syntaxonomic Analysis of Plant Communities

To analyze the different communities based on their plant composition, as well as the similarities and differences between them, a cluster analysis was performed to group plots into vegetation units based on a set of species and cover abundances. Data dissimilarity matrices were calculated using the Bray–Curtis dissimilarity index. A hierarchical cluster analysis was performed on this matrix using the mean agglomeration method (UPGMA), and the optimal number of clusters was determined using the Silhouette index [58]. A dendrogram was derived to illustrate the dissimilarities between samples and species, sorted according to the distance matrices [59]. Furthermore, to study the ecological gradients between the vegetation clusters, an ordination graph of sampling sites was created using the Non-Metric Multidimensional Scaling (NMDS) method. The latter is an unconstrained method which attempts to represent, as closely as possible, the pairwise dissimilarity between objects in a low-dimensional space, unlike maximizing the variance or correspondence between objects in an ordination, as other methods do [60]. We also passively projected the environmental variables measured in the field on the NMDS plots to highlight the ecological drivers between the vegetation clusters.

Furthermore, we conducted a syntaxonomic analysis of the plant communities based on the ecological interpretation, mainly following Zohary [61]. However, given that Zohary's work is somewhat dated and lacks detailed regional information, we compared our findings with the more recent analysis of vegetation types in Fars province [62]. To address this gap, species identified in our study but not listed in Zohary [61] were attributed to specific syntaxa based on the group divisions done by Khodagholi [62].

An investigation on bioindication values of the plant communities was carried out based on the scientific literature, considering the habitats that commonly host the most recurrent species within each community.

2.2.3. Evaluation of Plant and Communities of Conservation Interest

The natural and conservation status of the species found in the plots were cross-referenced with the Red Data Book of Iran [63], scientific literature [6,64–66], and the International Directives of CITES. New records and notes on species from the scientific literature were also evaluated.

2.2.4. Vegetation Mapping

The vegetation map was created through field surveys and photo interpretation. Indeed, for each vegetation type identified in the field, the extent and distribution within the perimeter of the archaeological site were estimated by recording the GPS coordinates of each area boundary The QGIS Software version 3.36 was utilized to map the distribution of the different vegetation units, providing a spatial representation of different plant communities. A photointerpretation of areas was also carried out, comparing collected data with orthophotos taken from Google Satellite.

Subsequently, we produced a map that illustrates the distribution of species with conservation interest, highlighting areas with the highest and lowest abundance among the different clusters.

2.2.5. Preliminary Evaluation of Recent Environmental Changes

The climate analysis involved meteorological data from Fars, sourced from nearby synoptic stations (Persepolis, Safashahr, and Arsenjan) through http://www.irimo.ir, (accessed on 11 July 2023). This analysis included diagrams covering the past 16 years (2006–2022), and we developed the occurring trends. We also conducted analytical diagrams focusing on the most recent 4 years to evaluate possible recent drastic changes.

We also evaluated the occurrence of further anthropic activities which could influence the climatic conditions of the site, analyzing the recent documentation referred to water management [67–71].

3. Results

3.1. Ecological and Syntaxonomic Characteristics of the Plant Communities and Their Bioindication Values

The resulting dendrogram of the 33 plots carried out in the site (Figure 3), based on similarities in species composition and cover abundances, highlighted the presence of seven main distinct clusters, which correspond to: 1. hilly grasslands; 2. grasslands dominated by *Stipa barbata* Desf.; 3. shrublands dominated by *Alhagi maurorum* Medik; 4. Grasslands dominated by *Bellevalia saviczii* Woronow; 5. grasslands dominated by *Glycyrrhiza glabra* L.; 6. ruderal vegetation of the Royal Garden watercourses; and 7. grasslands dominated by *Hordeum murinum* L. Three of them differ the most from all the others, in particular, in order of relevance, the groups 1, 2, and 3. The remaining four groups are divided into two subgroups (groups 4–5 and 6–7), which show a certain internal similarity:

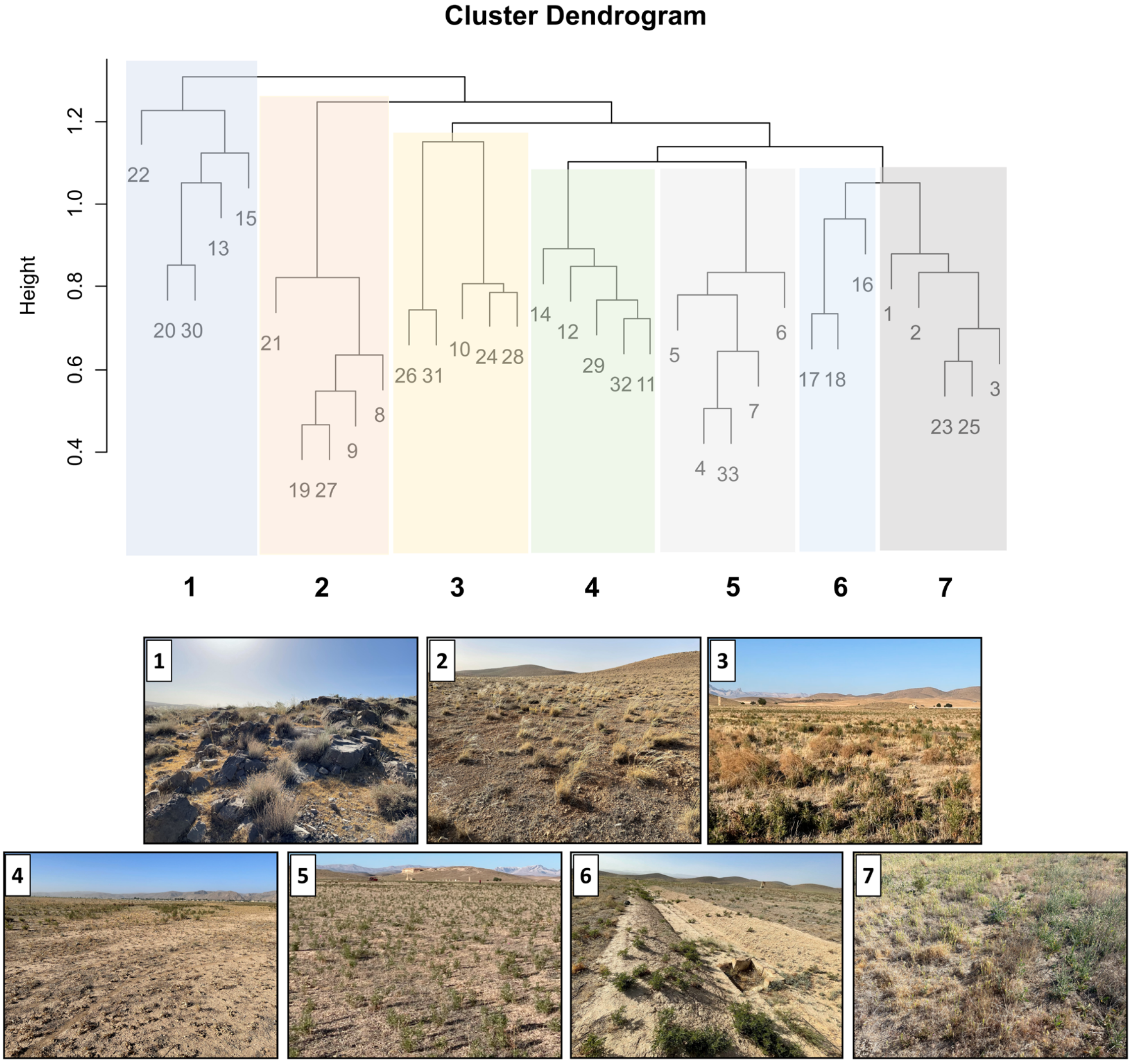

Figure 3. Dendrogram of vegetation trough cover data and corresponding pictures of vegetation types growing in the Pasargadae (May 2022). Plant communities (clusters): 1. hilly grasslands; 2. grasslands dominated by *Stipa barbata* Desf.; 3. shrublands dominated by *Alhagi maurorum* Medik; 4. Grasslands dominated by *Bellevalia saviczii* Woronow; 5. grasslands dominated by *Glycyrrhiza glabra* L.; 6. ruderal vegetation of the Royal Garden watercourses; and 7. grasslands dominated by *Hordeum murinum* L. The numbers not in bold from 1 to 33 indicate the different sampling areas.

The ordinations with the cluster arrangements in an ecological space resulting from the NMDS are displayed in Figure 4. This ordination confirms the cluster analysis results, regarding the organization of the groups. Two ecological gradients are evident: one along the *x*-axis from cluster 1 to cluster 5, and another along the *y*-axis from clusters 1 and 2 to cluster 7. The *y*-axis variability appears to be influenced by edaphic and geomorphological factors, since the observed hilly grasslands and grasslands dominated by *Stipa barbata* (clusters 1 and 2) grow in rockier and more sloped soils or with the presence of humps, and the other grasslands grow mainly in clay and loamy soils. The variability observed along the *x*-axis seems to be linked mainly to the anthropogenic disturbance, which has the highest values in clusters 7 and 3, characterized also by higher plant covers, and the lowest in clusters 1 and 2.

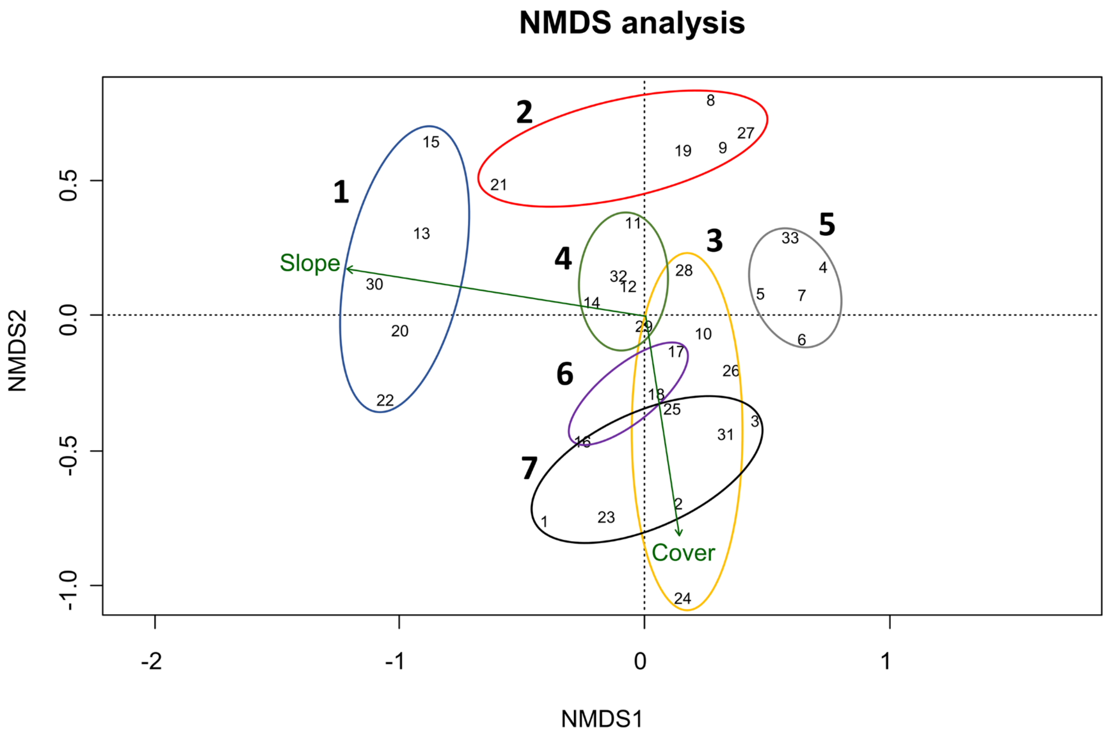

Figure 4. NMDS ordination of the vegetation samples carried out in the Pasargadae WHS, Iran (NMDS stress = 0.14; Shepard plot non-metric fit R^2 = 0.95 and linear fit R^2 = 0.78). Clusters are circled and over-imposed on NMDS plots. 1. Hilly grasslands; 2. Grasslands dominated by *Stipa barbata* Desf.; 3. Shrublands dominated by *Alhagi maurorum* Medik; 4. Grasslands dominated by *Bellevalia saviczii* Woronow; 5. Grasslands dominated by *Glycyrrhiza glabra* L.; 6. Ruderal vegetation of the Royal Garden watercourses; and 7. Grasslands dominated by *Hordeum murinum* L. The numbers not in bold from 1 to 33 indicate the different sampling areas.

The syntaxonomic analysis of the vegetation showed the presence of different alliances and orders of plant communities, which can be subdivided into the main categories of synanthropic vegetation and semi-natural grasslands (Table 1). The classes attributed to each category resulted in *Chenopodietea* Oberd. 1957 and *Secalinetea Orientalia* Zohary 1973, for the synanthropic vegetation, and *Artemisietea herbae-albae iranica* Zohary 1973 and *Astragaletea iranica* Zohary 1973 for the semi-natural grasslands (Tables 1, 2 and S1–S5) [61,62].

Table 1. Syntaxonomic scheme of the main resulting vegetation types.

1. SYNANTHROPIC VEGETATION
1.1 RUDERAL AND SEGETAL VEGETATION OF MAN-MADE HABITATS
CHENOPODIETEA Oberd. 1957
SECALINETEA ORIENTALIA Zohary 1973
Tricetalia 7apsica77a Zohary 1950
Prosopidion farctae segetale Zohary 1973
Triticetalia iranica Zohary 1973
Secalion cereale segetale Zohary 1973
Hulthemion persicae segetale Zohary 1973
2. SEMI-NATURAL GRASSLANDS
2.1 SEMI-DESERTS AND STEPPES VEGETATION
ARTEMISIETEA HERBAE-ALBAE IRANICA Zohary 1973
Artemisietalia iranica typica Zohary 1973
Artemisietalia iranica tragacantha Zohary 1973
ASTRAGALETEA IRANICA Zohary 1973

Table 2. Synoptic Table showing the classes of frequency (from I to V) of the species occurring among the different clusters. Clusters: 1. Hilly grasslands; 2. Grasslands dominated by *Stipa barbata* Desf.; 3. Shrublands dominated by *Alhagi maurorum* Medik; 4. Grasslands dominated by *Bellevalia saviczii* Woronow; 5. Grasslands dominated by *Glycyrrhiza glabra* L.; 6. Ruderal vegetation of the Royal Garden watercourses; and 7. Grasslands dominated by *Hordeum murinum* L. Life forms: Ch = chamaephyte, G = geophyte, H = hemicryptophyte, T = therophyte.

		Synoptic Table						
Clusters	**Life Form**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
***Artemisietalia iranica tragacantha* Zohary 1973**								
Stipa barbata Desf.	H	III	V	I	I		I	I
Launaea acanthodes (Boiss.) Kuntze	H	IV	II	II	V		III	III
Astragalus cancellatus Bunge	H		III	III	III		III	II
Medicago sativa L.	H		II	II	III		I	IV
Helichrysum leucocephalum Boiss.	H	IV						
Salvia macrosiphon Boiss.	Ch	II	I		I	III		II
Noaea mucronata (Forssk.) Asch. & Schweinf.	Ch	III	I		II			II
Centaurea balsamita subsp. *kermanensis* (Bornm.) Wagenitz	T	I	II	II				I
Centaurea bruguierana subsp. *belangeriana* (DC.) Bornm.	T	I			IV			I
Lomelosia olivieri (Coult.) Greuter & Burdet	T	III	I		II			
Senecio glaucus L.	T		I	I				IV
Astragalus cemerinus Beck	Ch	II	I					
Astragalus fasciculifolius Boiss.	H	I						
Hertia angustifolia (DC.) Kuntze	Ch		II					
Picris strigosa M.Bieb.	H	I			II		I	
Astragalus borraginaceus Rech.f.	H		I	II				
Phlomis persica Boiss.	H	I					II	
Zosima absinthifolia Link	H							II
Cousinia gracilis Boiss.	H				II			
Peganum harmala L.	Ch		I	I				
Phlomis aucheri Boiss.	H		II					
Phlomis orientalis Mill.	H	I			I			
Pimpinella aurea DC.	H	I						I
Reseda alba L.	H					I		I
Acantholimon serotinum Rech.f. & Schiman-Czeika	H	I						
Centaurea calcitrapa L.	H				I			
Cousinia leptomera Rech.f.	H					I		
Cousinia nekarmanica Rech.f.	H	I						
Polygonum hyrcanicum Rech.f.	H							I
Silene sisianica Boiss. & Buhse	T	I						
Stachys inflata Benth.	H		I					
***Artemisietalia iranica typica* Zohary 1973**								
Bellevalia saviczii Woronow	G		IV	II	V	IV	I	II
Boissieria squarrosa (Banks & Sol.) Nevski	T	IV	I	IV	IV		III	III
Taeniatherum caput-medusae (L.) Nevski	T	IV	II	II	IV	II		I
Euphorbia dracunculoides Lam.	T	I	III	III	I		II	
Dianthus crinitus subsp. *kermanensis* Rech.fil	H	IV						
Aegilops tauschii Coss.	T			I		I		
Aegilops crassa Boiss.	T				I	I	I	
Lactuca orientalis (Boiss.) Boiss.	Ch		I					I
Stipa hohenackeriana Trin. & Rupr.	H	I	II					
Bellevalia glauca (Lindl.) Kunth	G				II			
Crupina vulgaris Pers. ex Cass.	T	I						I
Diarthron lessertii (Wikstr.) Kit Tan	Ch	I						
Eryngium billardieri Delile	H			I				
Euphorbia sororia Schrenk	T						I	
Stipa lessingiana Trin. & Rupr.	H						I	

Table 2. *Cont.*

		Synoptic Table						
Clusters	**Life Form**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
***Astragaletea iranica* Zohary 1973**								
Achillea vermicularis Trin.	H		IV	III	V	V	I	II
Allium sphaerocephalon L.	G	I			III	IV		III
Onosma microcarpum DC.	H	II						
***Secalion cereale segetale* Zohary 1973**								
Glycyrrhiza glabra L.	G	I	IV	V	IV	V	III	IV
Lactuca serriola L.	T	I		IV	I	III	II	V
Zoegea leptaurea L.	T	III	III	II		II		II
Hyoscyamus reticulatus L.	G			II	III	III		
Medicago monantha (C.A.Mey.) Trautv.	T	I	I	I	I	III	I	
Consolida orientalis (J.Gay) Schrödinger	T			I		III		I
Medicago persica (Boiss.) E.Small	T	I	I				II	I
Sisymbrium irio L.	T				I	II		II
Alcea kurdica Alef.	H		III	I				
Centaurea virgata subsp. *squarrosa* (Boiss.) Gugler	H						I	I
Convolvulus argyracanthus Rech. f., Aellen & Esfand.	Ch	II						
Galium tricornutum Dandy	T							I
Sisymbrium irio L.	T	I				I		
Turgenia latifolia (L.) Hoffm.	T							II
Anchusa azurea Mill.	H						I	
Matthiola chenopodiifolia Fisch. & C.A. Mey.	T					I		
Reseda lutea L.	H		I					
***Hulthemion persicae segetale* Zohary 1973 and *Tricetalia iranica* Zohary 1973**								
Bromus tectorum L.	T	II	I	II			III	III
Gundelia tournefortii L.	H	IV	I					
Papaver argemone L.	T					I		III
Carthamus oxyacantha M.Bieb.	T	I						II
Koelpinia linearis Pall.	T				II			I
Valerianella szovitsiana Fisch. & C.A. Mey.	T					III		
Tragopogon graminifolius DC.	H					II		
Camelina hispida Boiss.	T	I						II
Lepidium draba L.	G	I					I	
***Prosopidion farctae segetale* Zohary 1973, *Triticetalia orientalia* Zohary 1949–50 and *Secalinetea orientalia* Zohary 1973**								
Alhagi maurorum Medik.	Ch		IV	V		II	I	
Alhagi pseudalhagi (M. Bieb.) Desv. ex B. Keller & Shap.	H		I	II	I		I	I
Centaurea solstitialis L.	H			I				III
Falcaria vulgaris Bernh.	T			I			I	IV
Gypsophila pilosa Huds.	G							II
Bongardia chrysogonum (L.) Spach	H				I			
Chenopodietea Oberd. (1957)	T							
Hordeum murinum subsp. *glaucum* (Steud.)	T			V	III	III	III	V
Cyanus depressus (M.Bieb.) Soják	H	II		II	III	II	II	V
Onopordum leptolepis DC.	G	III	I	IV	III	II	I	IV
Cynodon dactylon (L.) Pers.	H	I	I	II	V		I	I
Convolvulus arvensis L.	T			II		II	III	
Chardinia orientalis (L.) Kuntze	T	III	I	I				II
Erodium cicutarium (L.) ''Hér.	G			I				II
Scorzonera tunicata Rech.f. & Köie	H				II			
Tragopogon collinus DC	T			II	I		II	
Companions	T							
Nigella oxypetala Boiss.	T	I	III	II	II	V		II
Eremopyrum bonaepartis (Spreng.) Nevski	H		I	III	IV	IV	II	II
Festuca arundinacea Schreb.	H	III	I			III		I
Marrubium crassidens Boiss.	T	I						II

Table 2. *Cont.*

		Synoptic Table						
Clusters	**Life Form**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Crepis sancta subsp. *nemausensis* (P.Fourn.) Babc.	T			I	I			II
Tragopogon porrifolius subsp. *longirostris* (Sch.Bip.) Greuter	H						I	II
Chorispora tenella (Pall.) DC.	T				I			II
Descurainia sophia (L.) Webb ex Prantl	T			I				II
Hordeum spontaneum K.Koch	T			I	I			I
Marrubium vulgare L.	G		I			I		
Nonea caspica (Willd.) G.Don	T	I						II
Siebera nana (DC.) Bornm.	T	I	I					
Agrostis gigantea Roth	T	II						
Filago pyramidata L.	T	II						
Garhadiolus hedypnois Jaub. & Spach	T							II
Plantago lanceolata L.	H				I			
Rochelia disperma (L.f.) K.Koch	T					II		
Scabiosa persica Boiss.	T				II			
Barbarea plantaginea DC.	H				I			
Hordeum vulgare L.	T	I						
Leopoldia tenuiflora (Tausch) Heldr.	G		I					
Minuartia meyeri (Boiss.) Bornm.	T		I					
Moltkia gypsacea Rech.f. & Aellen	H	I						
Muscari neglectum Guss. ex Ten.	G				I			
Prunus arabica (Olivier) Meikle	P	I						
Rhaponticum repens (L.) Hidalgo	H		I					
Scirpoides holoschoenus (L.) Soják	G				I			
Solanum villosum Mill. (heterotypic synonym)	T			I				
Zeravschania membranacea (Boiss.) Pimenov	H						I	

The dominant species for each cluster, as evidenced by Tables 1 and S1–S5, were: for cluster 1, *Launaea acanthodes*, *Helichrysum leucocephalum*, and *Dianthus crinitus subsp. kermanensis*; for cluster 2, *Stipa barbata;* for cluster 3, *Alhagi maurorum*; for cluster 4, *Bellevalia saviczii*; for cluster 5, *Glycyrrhiza glabra;* for cluster 6, *Convolvulus arvensis* and *Tragopogon collinus;* and for cluster 7, *Hordeum murinum*. Such dominant species enhance the following bioindication values for the different clusters:

1. dry and windy rocky slopes of lands abandoned after extensive grazing [72–74];
2. dry and stony soils of semi-natural habitats [75];
3. disturbed areas and extreme dry conditions [72,76–78];
4. clayey soils [78];
5. silty-sandy alluvial deposits, subject to grazing and post-cultivation in steppe areas [79,80];
6. ruderal areas [17,81];
7. trampled areas [82].

Vegetation found in steppe soils was predominantly co-dominated by species from the genus *Astragalus*, and is commonly associated with extensive pastures undergoing post-abandonment succession.

3.2. Naturalistic Interest of the Species and the Distribution in the Area

Fifteen endemic species of conservation interest were found at the site, and their distribution and conservation status are detailed in Table 3. These endemic species fall into three distribution groups (Table 3). Most are distributed both in Fars and other Iranian regions (12 species); *Cousinia nekarmanica* and *Astragalus cemerinus* were not reported before [6] for the Fars region. Therefore, this site represents their only regional station; *Acantholimon serotinum* is endemic to the Fars region; *Cousinia gracilis* Boiss. Represents a new discovery within the site, which was not reported by Hosseini et al. [6].

Table 3. Endemic species to Iran recorded in the site and their conservation status, defined following Rechinger [56] and the Red Data Book of Iran [63].

Family	Species	Rechinger	Distribution	Conservation Status
Apiaceae	*Zeravschania membranacea* (Boiss.) Pimenov		Fars and other Iran regions	DD
Asteraceae	*Centaurea balsamita* subsp. *kermanensis* (Bornm.) Wagenitz		Fars and other Iran regions	LR
Asteraceae	*Cousinia gracilis* Boiss.	Iran Endm	Fars and other Iran regions	DD
Asteraceae	*Cousinia nekarmanica* Rech.f.		Other Iran regions	LR
Asteraceae	*Helichrysum leucocephalum* Boiss.		Fars and other Iran regions	LR
Asteraceae	*Hertia angustifolia* Kuntze		Fars and other Iran regions	LR
Boraginaceae	*Moltkia gypsacea* Rech.f. & Aellen	Iran Endm	Fars and other Iran regions	LR
Fabaceae	*Astragalus cemerinus* Beck		Other Iran regions	LR
Fabaceae	*Astragalus fasciculifolius* Boiss. subsp. fasciculifolius	Iran Endm	Fars and other Iran regions	LR
Fabaceae	*Medicago persica* (Boiss.) E.Small		Fars and other Iran regions	LR
Lamiaceae	*Phlomis aucheri* Boiss.	Iran Endm	Fars and other Iran regions	LR
Lamiaceae	*Phlomis persica* Boiss.	Iran Endm	Fars and other Iran regions	LR
Plumbaginaceae	*Acantholimon serotinum* Rech.f. & Schiman-Czeika	Iran Endm	Fars	DD
Polygonaceae	*Polygonum hyrcanicum* Rech.f.		Fars and other Iran regions	LR
Solanaceae	*Hyoscyamus kotschyanus* Pojark.	Iran Endm	Fars and other Iran regions	LR

The IUCN Conservation Status of each species obtained from [63] is reported in Table 3, showing that most of the species are considered at Low Risk (LR), but also three species are data deficient (DD), including *Acantholimon serotinum*, which is Fars endemic.

Table 4 shows the distribution of the endemic species with conservation interest among the different clusters. Cluster 1, which corresponds to the hilly areas furthest from visitor paths, is the one that holds the highest number of species with conservation interest, with a total of nine species, including five found exclusively here. Cluster 2, i.e., grasslands dominated by *Stipa barbata*, occurring sporadically within the site, comes next, with five species, two of which were exclusive. Combining the previous data, we can also note that among the semi-natural grasslands, *Artemisietalia iranica tragacantha* Zohary 1973, within the class *Artemisietea herbae-albae iranica* Zohary 1973, resulted in the richest in terms of species composition, particularly within clusters 1 and 2.

Clusters 3, 4, 6, and 7 appear similar, with two or three species, one of which was exclusive, while Cluster 5, which comprises grasslands dominated by *Glycyrrhiza glabra*, exhibited the lowest richness, with only one species and no exclusive ones.

By analyzing the distribution of plant communities, as derived from QGIS 3.36 software, we can note the significant heterogeneity in the distribution and size of the clusters (Figure 5). Clusters 5, 1, and 7 have the largest size, with the first predominantly in the central part of the site, the second covered almost the entire northernmost part, and the third was mainly found in the southernmost part. The remaining clusters exhibit a more scattered presence: clusters 2 and 3 are sparsely distributed within the site, cluster 4 stretches across a central strip, corresponding to a dry riverbed, and cluster 6 was mainly found in a small area of the central part, around the remnants of the Royal Garden watercourses (Figure 5A).

Table 4. Distribution of the endemic species with conservation interest among the different clusters. For each cluster, the species were assigned frequency classes using Roman numerals I to V, except for cluster 6, which contains three reliefs, in which Arabic numerals 1 to 3 were used. The average coverage values are given in superscript. 1. hilly grasslands; 2. grasslands dominated by *Stipa barbata* Desf.; 3. shrublands dominated by *Alhagi maurorum* Medik; 4. Grasslands dominated by *Bellevalia saviczii* Woronow; 5. grasslands dominated by *Glycyrrhiza glabra* L.; 6. ruderal vegetation of the Royal Garden watercourses; and 7. grasslands dominated by *Hordeum murinum* L.

	Clusters						
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Acantholimon serotinum Rech.f. & Schiman-Czeika	I $^{+}$						
Astragalus cemerinus Beck	II ^{1}	I $^{+}$					
Astragalus fasciculifolius Boiss. subsp. fasciculifolius	I ^{5}						
Centaurea balsamita subsp. *kermanensis* (Bornm.) Wagenitz	I $^{+}$	II $^{+}$	II $^{+}$				I $^{+}$
Cousinia gracilis Boiss.				II $^{+}$			
Cousinia nekarmanica Rech.f.	I $^{+}$						
Helichrysum leucocephalum Boiss.	IV ^{2}						
Hertia angustifolia Kuntze		II ^{1}					
Hyoscyamus kotschyanus Pojark.			II $^{+}$	III $^{+}$	III $^{+}$		
Medicago persica (Boiss.) E.Small	I $^{+}$	I $^{+}$				2 $^{+}$	I $^{+}$
Moltkia gypsacea Rech.f. & Aellen	I $^{+}$						
Phlomis aucheri Boiss.		II $^{+}$					
Phlomis persica Boiss.	I $^{+}$					2 $^{+}$	
Polygonum hyrcanicum Rech.f.							I $^{+}$
Zeravschania membranacea (Boiss.) Pimenov						1 $^{+}$	
Total	9	5	2	2	1	3	3
Species found exclusively in the specific cluster	5	2	0	1	0	1	1

3.3. Warming and Desiccation of the Area as Threats to Plant Biodiversity

The climatic data from 2006 to 2022 revealed an increasing trend in temperature and a fluctuation in precipitation values, marked by a significant alteration in average precipitation (222.8 mm), with variations from 120 mm to 314 mm. More recently, despite a peak in average rainfall in 2019 (Figure 6a), the overall trend indicated a relevant decrease in precipitation during traditionally rainy months, especially in Spring and in a more limited way throughout the Fall season (Figure 6b–e). This decline is evident when comparing the monthly rain-temperature chart for the last four years, and the lowest precipitation amounts were recorded in 2008, 2017, and 2022.

Adding to the climatic challenges, the Polvar River, like all watercourses in the province of Fars, has been experiencing a gradual desiccation influenced by a combination of increasing warming and other human interventions, such as the construction of dams and the considerable exploitation for irrigation purposes, that further exacerbated the dryness [67,68,70]. Since the mid-1990s, episodes of drought have become increasingly frequent, significantly affecting the river's flow [67,68,83]. Currently, this river is completely dried up, marking a significant shift from its past status as a perennial river.

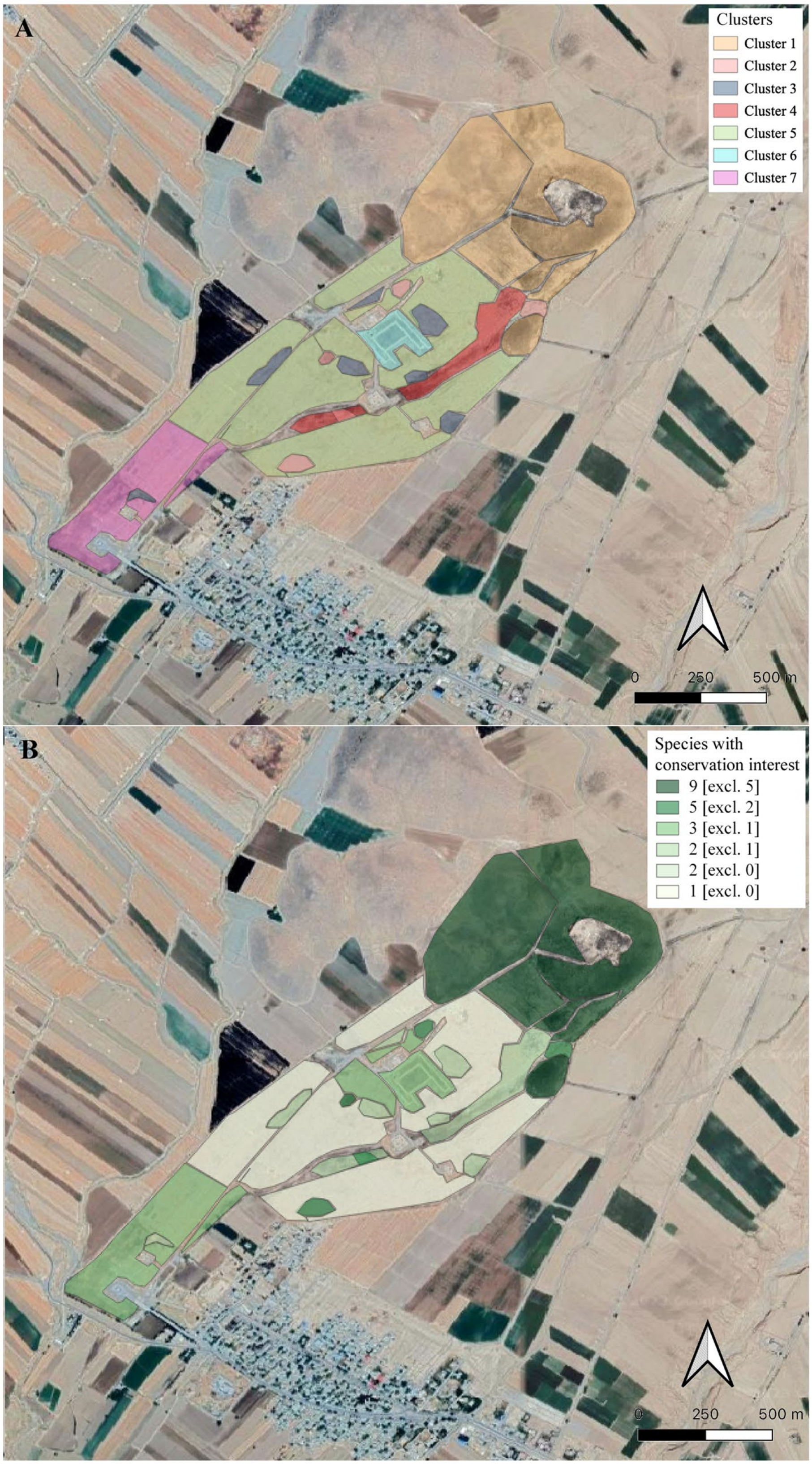

Figure 5. Vegetation maps of the Pasargadae WHS elaborated with QGIS Software, showing: (**A**) the distribution of the different clusters, and (**B**) the distribution of the species with conservation interest that occurred within the clusters considering both the total amount and the presences exclusively found in the specific cluster (in parenthesis).

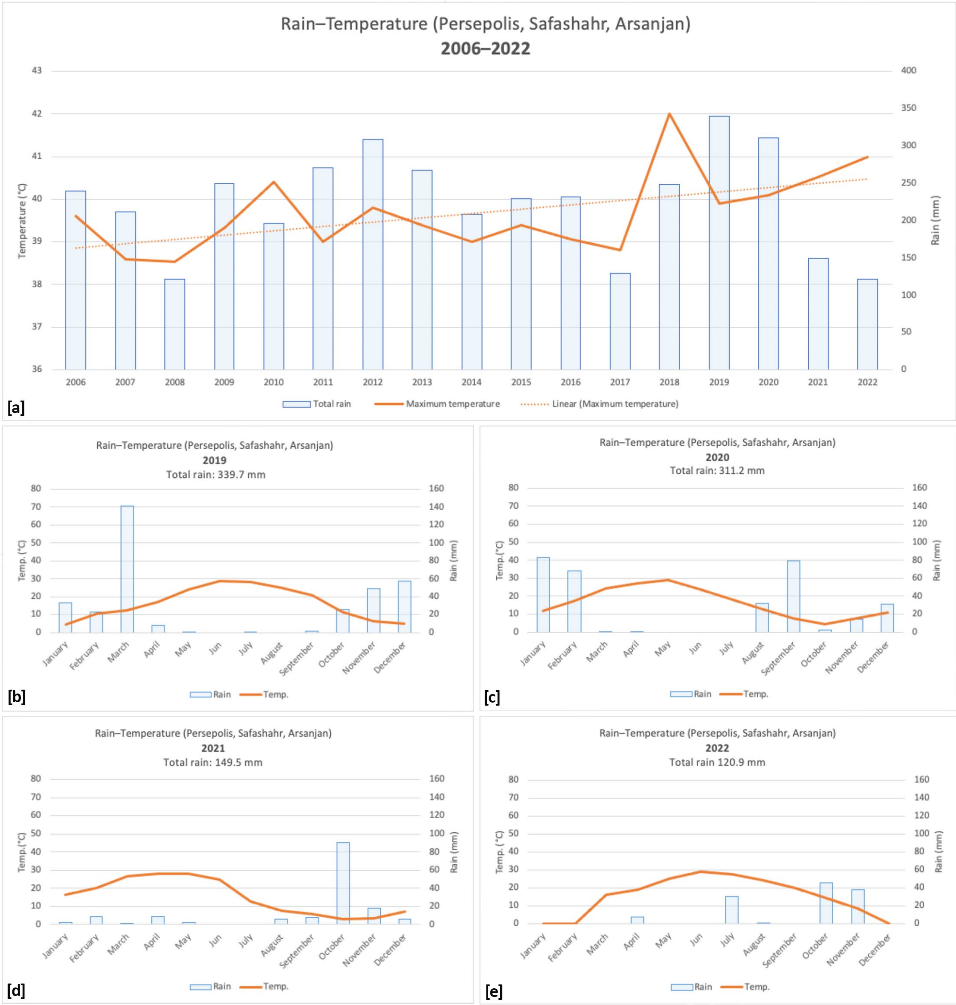

Figure 6. The chart of total rain and maximum temperature of three synoptic Fars stations (Persepolis, Safashar, and Arsenjan): (**a**) the annual chart during 2006–2022; the monthly bioclimatic variation in (**b**) 2019, (**c**) 2020, (**d**) 2021, and (**e**) 2022.

4. Discussion

This pioneering research on vegetation in archaeological sites of Iran contributes to the knowledge of plant communities in archaeological areas, particularly in arid or semi-arid environments, such as in Iran.

Previous studies on the flora of the Pasargadae site and its interaction with stone monuments revealed the importance of understanding the microhabitat of plant colonization on the remaining structures as a tool for controlling biodeterioration phenomena [17,49]. Additionally, the plant diversity of the site [6] and the distribution of the endemic species with conservation interest emphasized the importance of conservation strategies that consider both the natural and cultural values of the site [5,18,24,33,84]. This is particularly important in the context of plant diversity, as the conservation of these sites can help to ensure the protection of plant diversity [39,85].

In this contribution, we have expanded the syntaxonomical attribution of species missing in Zohary [61] to their respective syntaxa, achieved through comparisons with species groupings made by Khodagholi [62].

The presence of the class *Astragaletea iranica* Zohary 1973 is especially noteworthy, as it is typically associated with mountainous environments. Its occurrence in this context likely reflects dynamics related to ecological refuges [61].

The vegetation primarily influenced by human activity is predominantly represented by the *Secalinetea Orientalia* Zohary 1973 class, one of the most prevalent vegetation classes in the Middle East. This class represents the weed communities commonly observed in non-irrigated winter and summer crops. It often occupies abandoned fields that have become partially overgrown by tragacanth astragals. Consequently, this community appears to represent an early post-agricultural phase in the succession towards *Artemisietea herbae-albae iranica* Zohary 1973 communities [61]. This class was more frequent within clusters 3, 4, and 5. The *Chenopodietea* Oberd. (1957) class, notably prevalent in clusters 6 and 7, is characterized by synanthropic vegetation dominated by annual and biennial nitrophilous and semi-nitrophilous species thriving in ruderal and disturbed environments [86]. This component is predominantly found within the site in areas closest to the most trafficked visitor paths and subjected to trampling.

This also explains the similarity in species composition (Figures 3 and 4) and the distribution of the endemic species with conservation interest among the different clusters. Indeed, the highest number of species with conservation interest held by clusters 1 and 2 (Table 4) is in accord with findings made by several authors, namely that when grazing is conducted in a non-intensive manner, it tends to promote greater biodiversity, and the effects of such practices can persist for an extended period of time [87–92].

Additionally, the higher number of species with conservation interest observed in clusters 1 and 2 can be attributed to the microhabitats formed by variations in bedrock and erosion processes. These conditions reduce the competition of dominant species and foster the growth of therophyte species that require environments with lower nutrient and water availability [93,94].

Plant bioindication values have provided significant insights into historical human activities and land-use practices, such as cultivation, corresponding to cluster 5, located in the central and flat parts of the site (see also Figure 5). While the activities proposed by bioindication lack certainty, the likelihood of their occurrence in the region is notably high, particularly in light of the land use management pattern observed in several rangelands of Iran [95]. The land use with extensive grazing has primarily impacted the hilly areas (cluster 1), which are rockier and more sloped, making them less suitable for cultivation. The clayey soils in cluster 4, which likely correspond to a dry riverbed, and the silty-sandy alluvial deposits in areas of cluster 5, indicated fertile soils suitable for cultivation. The ruderal communities in clusters 6 and 7 are instead due, respectively, to the limited availability of soil for the rock outcrop in the remnant of the Royal Garden watercourses and to the influences given from visitor trampling.

Furthermore, the study has highlighted the importance of vegetation maps as a tool for managing different habitats within the site. These maps are instrumental in identifying areas that require protection from anthropogenic pressures such as trampling and mowing, as well as areas hosting invasive species that need to be managed [18,96]. In fact, human activities, including livestock grazing, mowing, and the use of herbicides, also contribute significantly to vegetation distribution [40,97], as seen in the differential coverage around Cyrus the Great's Tomb and the more natural northern hills. This distinction is crucial for developing targeted conservation strategies that respect the site's dual natural and historical significance.

Integrating naturalistic and cultural values in conservation planning ensures not only the preservation of biodiversity, but also the continuity of the landscape's historical narrative [98,99]. Additionally, for the valorization of the Royal Garden of Cyrus the Great, great information could be obtained from vegetation surveys, and analyzing the plant species within and around the presumed location of the lost garden can contribute to the valorization scenario by respecting both ancient and current landscapes [96]. The phytosociological syntaxa could also support the understanding of ancient (cereal and pulse) crop husbandry regimes [100,101].

Finally, the observed recent shifts in precipitation and temperature patterns may have profound implications for the conservation of biodiversity and cultural heritage. The decrease in rainfall of recent years, particularly during critical growth phases, not only may impact phenological patterns and distribution of plants [102–104], but also may threaten species that already have small ranges [105–108], increasing the risk of extinction for many species [109–113]. This is especially concerning for the endemic and restricted-range species found in the study area, which exhibit a heightened vulnerability to environmental change [114]. Such species are vital not only for their intrinsic ecological value, but also as indicators of historical land-use practices, which are part of the cultural narrative of the site.

When looking at our previous floristic data collected in 2019 [6], we can now underline some changes in the dominant species, and an anticipation of the flowering period, such data underscores the increasing stresses induced by the warming and desiccation of the area, posing challenges to the naturalistic value of the site. In general, the impact of climate change in northern Fars will determine a reduction of precipitation in the future [71] and an increase in the duration and severity of drought [115]. Based on the climate scenarios, by 2025, the Fars region (in Tashk, Bakhtegan, and Maharlu lakes) will experience a 5.67–15.15% reduction in runoff [116,117].

5. Conclusions

This research has advanced our understanding of vegetation in Iran's archaeological sites, shedding light on plant communities and their interactions with human activity and the natural environment, which have been relatively underexplored in the country. Through vegetation analyses and classification within a syntaxonomic framework, the research has yielded significant findings, particularly in identifying rich species compositions within different vegetation classes. Notably, it highlighted the importance of understanding both natural and human-induced influences on vegetation distribution, emphasizing the critical role of human activities in shaping plant communities.

Furthermore, the bioclimatic analysis in recent years dramatically confirmed the impact of climate change on vegetation patterns and biodiversity, underscoring the urgent need for adaptive conservation strategies. The observed shifts in temperature patterns and the increasing dryness conditions pose significant challenges to both plant diversity and cultural heritage preservation, necessitating proactive measures to mitigate these impacts within the broader context of cultural heritage preservation and sustainable management practices.

Moreover, the work emphasized the importance of integrating ecological and cultural values in conservation planning. By considering both naturalistic and cultural aspects, conservation efforts can ensure the preservation of biodiversity while safeguarding historical monuments.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su16093784/s1. Table S1: Analytic table of cluster 1, hilly grasslands; Table S2: Analytic table of cluster 2, grasslands dominated by *Stipa barbata* Desf.; Table S3: Analytic table of cluster 3, shrublands dominated by *Alhagi maurorum* Medik.; Table S4: Analytic table of clusters 4–5, respectively, grasslands dominated by *Bellevalia saviczii* Woronow and grasslands dominated by *Glycyrrhiza glabra* L.; Table S5: Analytic table of clusters 6–7, respectively, ruderal vegetation of remnant of the Royal garden watercourses and grasslands dominated by *Hordeum murinum* L.

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