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Edaphic Drivers Influencing Forage Grasslands in Bujagh National Park, Iran

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Abstract: The edaphic and environmental changes in Bujagh grasslands have led to a gradual decline in the wintering waterbird populations in the associated national park. This has particularly affected forage habitats for birds, especially migratory geese. Our aim was to identify the reasons for the loss of habitat quality by examining the structure of the plant community and the edaphic factors that have been instrumental in shifting the grass community pattern to a Rush–Rubus type along the succession route. Bujagh National Park is surrounded by marine, riverine fresh water, and lagoon habitats, and the seasonal floodings of the Sefidrud and Ushmak rivers impact the grassland area along the deltaic pathway to the Caspian Sea. We used the TWINSPAN classification function to extract plant groups and their dominant species. Subsequently, we analyzed land cover changes in the study area over two times (2010 and 2020) to identify alterations in the coverage of main plants and land uses. Following the evaluation of unconstrained ordination methods and the selection of NMDS ordination, we compared the dominant species of groups to the main edaphic predictors. The results indicated that the chemicals and heavy metals in the soil did not play a direct role in the shift from grassland to Rush–Rubus plant type. However, these elements could have a significant impact on the evolution of the structure and the competitive capability among the main dominant species of the grass group. In conclusion, the dominance of the Rush–Rubus type is likely related to other unmeasured environmental and anthropogenic factors that support and enhance their reproductive attributes and herbal proliferation in the grassland territory.

Keywords: migratory waterbirds; land cover change; edaphic drivers; forage grassland

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Citation: Mahfouzi, M.; Hamidian, A.H.; Kaboli, M. Edaphic Drivers Influencing Forage Grasslands in Bujagh National Park, Iran. *Resources* **2024**, *13*, 29. https://doi.org/10.3390/resources13020029

Academic Editor: Antonio A. R. Ioris

Received: 25 October 2023
Revised: 5 February 2024
Accepted: 7 February 2024
Published: 13 February 2024

1. Introduction

Managing natural grasslands is vital for reinforcing bird abundance and foraging grounds, making these purposes important priorities in conservation affairs [1–4]. However, certain human activities, such as burning natural grasslands [5], livestock grazing and mowing [6–10], overuse of pesticides and chemical fertilizers in agricultural lands, fragmentation of natural grasslands [11–14], and determination of protective buffers, have crucial effects on the growth and sustaining of grassland community and foraging bird populations [15]. For wintering migratory birds that travel long distances, the presence or lack of safe wintering habitats is a determinant factor in their attendance in each area [16,17]. Unpleasant events can affect the survival and reproduction of migratory birds and disturb the population dynamics during the breeding season [17–20]. If wintering habitats along the migration period have sufficient food resources, they will provide the basis for the survival of birds across long distances [18,21,22]. This matter helps the regulation of mating time and well-timed reproduction [23] and increases hatching and fledging success [19,24]. In winter, a heterogeneous structure of vegetation can provide thermal protection [25], improve foraging opportunities [25,26], and decrease predation risk [27] for birds.

Bujagh National Park, along with its affiliated Ramsar site wetlands, is a crucial habitat for both the wintering and nesting of migratory birds in the northern region of Iran. To date, 236 bird species have been documented at this site, and national statistics indicate that approximately 30 thousand birds visit the area annually across all four seasons [28]. Notably, the Bujagh wetland serves as the primary wintering ground for threatened species, such as the geese group. These birds attend in their habitats with numerous populations in the associated grasslands, as their food preferences primarily consist of taxa from the Poaceae and Fabaceae families, which are the predominant families in the structure of the current grasslands [29,30].

The Bujagh grasslands, located at the mouth of the Sefidrud River delta, have undergone a succession process with its fair share of ups and downs. Over the last 30 years, the outlet of the Sefidrud to the Caspian Sea has changed at least three times due to various factors, such as river sediments, earthquakes, floods, and changes in sea wave direction [31–34]. These events have caused the grasslands to shrink or even be destroyed along the succession trajectory. The main plants of the grasslands have adapted to seasonal flooding and soil moisture, but some species disappear in permanent flooding conditions. In the past two decades, the inundation condition in grassland was significantly altered, resulting in a reduction in the periodic waterlogging of the soil. In fact, the soil water table has deeply retreated, and thereafter, loaded farming drainages have affected soil quality and vegetative conditions. Recent edaphic changes in the grassland territory have led to the appearance of two non-forage plants, spiny rush (*Juncus acutus*) and holly ramble (*Rubus sanctus*). These changes underscore the evolving nature of the Bujagh grasslands and the complex interplay of environmental factors shaping their ecological dynamics.

The gradual disappearance of birds feeding beds has resulted in a reduction in the wintering population in the area. This issue has particularly affected the presence of graylag geese (*Anser anser*) and ruddy shelducks (*Tadorna ferruginea*) [35]. Changes in soil quality may be attributed to the presence of newly discovered chemicals and the biological characteristics of the ecosystem [36,37]. Therefore, this research aims to detect land cover trends and identify the possible relationship between edaphic factors and the gradual evolution of grass communities using ordination methods. These methods determine significant factors in line with the changes of gradient in species [38], helping us to understand the dominant plant tendencies and the role of edaphic factors. This issue will enable us to make precise decisions to achieve restoration objectives and adopt the necessary suggestions that lead to the improvement of habitat quality, the revival of forage grounds, and the prosperity of biodiversity in Bujagh National Park in the future.

2. Methods and Materials

Our research was conducted in the grasslands of Bujagh National Park, located on the southwest coast of the Caspian Sea in northern Iran (49°54′38″ to 49°56′23″ E and 37°26′37″ to 37°28′19″ N). The Iranian Department of Environment (DoE) designated this national park in 1975, and its lagoons were later recorded under the international wetlands of the Ramsar sites [28]. The area receives an annual rainfall of up to 1900 mm [39], and the elevation of the park lands varies between −24 and −28 m, with a minor slope of less than 2%. The Sefidrud River flows from the south to the Caspian Sea, passing through the middle of the park (see Figure 1). Bujagh National Park represents multiple habitats, including riverine freshwater, brackish lagoons (such as the Bujagh and Kiashahr lagoons), grasslands, shrublands, and sandy coastal dunes. The marshy habitats serve as key areas for spawning and nursery grounds for a variety of fish species. Additionally, these habitats offer a wintering ground for thousands of migratory waterbirds, such as the graylag goose (*A. anser*), ruddy shelduck (*T. ferruginea*), lesser white-fronted goose (*Anser erythropus*), greater white-fronted goose (*Anser albifrons*), dalmatian pelican (*Pelicanus crispus*), white-headed duck (*Oxyura leucocephala*), greater spotted eagle (*Aquila clanga*), and sociable lapwing (*Vanellus gregarius*) [35,40].

Figure 1. Location of the study area and sampling grids in Bujagh National Park, northern Iran.

The marsh grasslands and sand-dune landforms in the northern part of the park have remained largely unchanged despite the gradual lowering of the Sefidrud riverbed due to sedimentation over the last few decades. The Bujagh lagoon, located to the west of the park, is sustained by the Ushmak drainage streams. The affiliated freshwater habitats are situated at the far western end of the lagoon and are characterized by clusters of reeds (*Phragmites* sp. and *Typha* sp.). In contrast, the brackish southern and eastern shores are covered by grasses and shrubs. The sandy dunes in the north and northwest of the area are adorned with saline scrubs and sea rushes, extending to the Caspian shore. The grasslands in the area are subject to periodic flooding and prolonged inundation during humid periods, occasionally experiencing a dedicated disappearance, while the deltaic landscape undergoes permanent alterations. However, the grasses can withstand inundation conditions under a normal flooding regime.

In respect of botany, the central portion of the study area is characterized by common knotgrass (*Paspalum distichum*) and dallisgrass (*Paspalum dilatatum*). The eastern part of the area is dominated by shrubs, such as spiny rush (*Juncus acutus*) and holly ramble (*Rubus sanctus*). In the northern region, sea rush (*Juncus maritimus*) is predominantly found on salty sand dunes near the Caspian coast. Towards the south and southeast border of the area, paddy fields are located, which are surrounded by strips of common alder (*Alnus glutinosa*). The main human threats to the study area include the conversion of dried wetland areas to agricultural lands, urban expansion, livestock overgrazing, and illegal hunting. These threats have been identified by various studies, such as [29,41,42].

2.1. Study Design and Data Collection

We used a random-systematic sampling method to conduct an inventory of the plant population. The study area was divided into 250 × 250 m grid cells, encompassing a total of 112 cells. Subsequently, 23 cells (20% of grid cells) were selected for surveying, while 89 cells remained unsurveyed (refer to Figure 1). Within each grid cell, we established five plots measuring 5 × 5 m. One plot was positioned at the centroid of each cell, two plots were located at the top left and top right, and the remaining two plots were placed at the bottom left and right sections of the cell, resulting in a nested sampling design. This approach yielded 115 sample plots, covering a total area of 2875 m^2 within the study area (Figure 1). The plant composition was determined based on the percentage of plant cover within each sample unit, which was then transformed to the Braun–Blanquet scale [43] to facilitate classification and correspondence analysis. In total, plant frequency, species indices (e.g., richness, diversity, and evenness), as well as the habitat and life forms of plant species, were measured using methods outlined in [44–46]. Soil samples were then collected from the selected habitats of dominant species; overall, 33 quadrats where vegetation samples were taken, and their concentrations were measured using an ICP-MS instrument. The measured data were normalized and standardized to homogeneous data before undergoing ordination analysis [47–49]. To survey the soil moisture levels approximately, the distance of each plot to water ponds was measured using the Google Earth environment (see Table 1).

Table 1. List of soil chemicals and heavy metals elements used in the research.

Data Group	Abbr.	Variables	Units
Group1: Soil chemicals and moisture	EC	Electrical Conductivity	µmhos/cm
	pH	Pressure of Hydrogen	-
	Sand	Sandy texture	%
	Silt	Silty texture	%
	Clay	Clay texture	%
	CO_3	Carbonate	meq/li
	HCO_3	Bicarbonate	meq/li
	Ca	Calcium	µg/g
	Mg	Magnesium	µg/g
	K	Potassium	µg/g
	Na	Sodium	µg/g
	SOM	Solid Organic Matter	%
	N	Total Nitrogen	%
	Moist	Distance to ponds	meter
Group2: Soil heavy metals	Fe	Iron	µg/g
	Al	Alumina	µg/g
	As	Arsenic	µg/g
	Cd	Cadmium	µg/g
	Co	Cobalt	µg/g
	Cr	Chromium	µg/g
	Cu	Copper	µg/g
	Mn	Manganese	µg/g
	Ni	Nickel	µg/g
	Pb	Lead	µg/g
	Si	Silica	µg/g
	Zn	Zinc	µg/g

2.2. Statistical Processing

Land cover changes in Bujagh were surveyed over a two-year period. We used images from September 2010 captured by the TM sensor of Landsat 5 and images from September 2020 captured by the OLI sensor of Landsat 8, which were obtained from the USGS website.

These images were free of cloud cover and geo-referenced based on the UTM coordinate system, zone 39N. Image preprocessing and classification were performed using the ENVI software (Version 5.3.1), and the additional processing was conducted using the ArcGIS software (Version 10.8). To classify the images, we used the Maximum Likelihood method and ground truth data collected from field visits and Google Earth. The accuracy and correctness of the classification were evaluated and confirmed using control points collected from the mentioned sources. To compare land cover changes between the two-time year (2010 and 2020), we used the Cross-tabulation function on two maps. This method allowed us to determine the number of shifted pixels across the two images, as well as the direction and trend of changes, with precision.

To identify the dominant and index plant species across sampling units, we employed the TWINSPAN cluster analysis method, a classification technique embedded in the JUICE ver. 7.1 software [50–54]. This method compares sample pieces based on the presence or absence of species and groups together those with more similarity. As a result, we obtained plant groups and a list of diagnostics, stable, and dominant species. For ordination analysis, we constructed a dominant species matrix based on plants that significantly correlate with the community structure. A total of 13 species and 33 samples were included in the species matrix, with five locational replicates for each species. The standardized soil chemicals and heavy metals (as shown in Table 1) were analyzed in two separate matrices but with the same sample plots used in the species matrix.

To determine the type of linear or non-linear ordination analysis, we adopted the criterion of the gradient length from the theory of Smilauer and Leps [43]. To analyze the overall community pattern, we used unconstrained ordination methods, including Detrended Canonical Analysis (DCA), Non-metric Multidimensional Scaling (NMDS), and Principal Component Analysis (PCA) from the Vegan package in R ver. 4.3.2. We also used the Procrustean rotation test to evaluate the goodness of fit of the ordinations and to determine the most appropriate concordance of the dominant plants with two matrices of edaphic elements [47,53–56].

3. Results

3.1. Floristic Description and Classification

In the floristic inventory of the study area, 65 taxa from 30 genera were identified in 115 samples, classified as two vascular, 47 dicotyledonous, and 77 monocotyledonous. The richest families in the area were Asteraceae, with 10 taxa; Poaceae, with seven taxa; and Fabaceae and Cyperaceae, each with five taxa. Table 2 shows the measurement of diversity and abundance indices in all samples.

Table 2. Summary of measured indices for all samples in the study area.

Indices	Min	Mean	Max	SD	CV
Diversity index (Shannon–Wiener)	0	1.70	2.86	0.84	49.4
Diversity index (Simpson index)	0	0.71	0.94	0.29	40.8
Species richness (number of species)	1	7.69	18	4.52	58.8
Species evenness (relative abundance index)	0.54	0.94	0.99	-	-

Following the classification and grouping results in TWINSPAN, three main groups were identified. A synoptic table was then used to extract the specific species of each group, in which the dominant, constant, and diagnostic species were recognized. In selecting dominant and indicator species for each group, the degree of species fidelity was considered as a criterion. The threshold limit for diagnostic species was set at an abundance percentage greater than 40%, for constant species greater than 50%, and for dominant species greater than 60%. The first group was characterized by the dominance of holly bramble (*R. sanctus*) and spiny rush (*J. acutus*), the second group by spurge (*Euphorbia granulata*), sea holly (Eryngium caeruleum), and Bermuda grass (*Cynodon dactylon*), and the third group by the presence of strawberry clover (*Trifolium fragiferum*) and white clover (*Trifolium repens*).

During the process of classifying sample plots, 25 plots were assigned to group 1. These plots are situated along the Sefidrud coast and extend up to the seacoast. Group 1 is characterized by the presence of opportunistic and newly discovered species, including spiny rush and holly bramble, which are dominant in a quarter of all samples. These are perennial stands with rhizomatous roots. The accumulation of sediments along the

Sefidrud coast has heaped some parts higher than other lands, which occasionally emerge from seasonal waterlogging. These heaps have provided suitable conditions for the prevalence of these plants. The second group includes 14 sample plots, dispersed mostly in the southern to southeastern part of the study area. The species *E. granulata*, *Plantago lanceolata*, *E. caeruleum*, and *C. dactylon*, which were identified as annual herbs in the area, are representative of this group. Group 3 is defined by 76 plots covering a wide expanse within the study area. The group includes grasses with perennial stands, modified to rhizomatous roots that play a significant role in grassland stabilization and support forage food for migratory birds. Key species in this group are *T. fragiferum*, *T. repens*, *P. distichum*, and *P. dilatatum*. Table 3 shows the characteristics of the plant groups that resulted from the TWINSPAN performance.

Table 3. Characteristics of the diagnostics, constant, and dominant plants in the groups that resulted from the TWINSPAN analysis.

Group	Scientific Name	Abbr.	Family	Habitat	Life Form	Distribution
one	*Juncus acutus* L.	Ju.ac	Juncaceae	WP (Hyg), WSD, Pl	Geo	SCOS
	Juncus maritimus Lam.	Ju.ma	Juncaceae	WSD, WP, Pl	Geo	ES, M
	Rubus sanctus Schreb.	Ru.sa	Rosaceae	Ru, Aq	Pha	Pl
two	*Cynodon dactylon* (L.) *Pers.*	Cy. da	Poaceae	Pl	Hem	Pl
	Plantago lanceolata L.	Pl.la	Plantaginaceae	WSD, SD	Hem	ES, IT, M
	Eryngium caeruleum M. Bieb.	Ery.ca	Apiaceae	Pl, WSD	Hem	ES, IT, M
	Euphorbia granulata Forssk.	Eu.gr	Euphorbiaceae	WSD, Ru, Pl	Thr	IT
	Euphorbia helioscopi L.	Eu. he	Euphorbiaceae	Pl, Ru	Thr	ES, IT, M
	Pennisetum glaucum (L. *R.Br.*)	Pe.gl	Poaceae	WSD, Ru	Thr	Pl
three	*Trifolium fragiferum* L.	Tr.fr	Fabaceae	WSD, Ru	Geo	Pl
	Trifolium repens L.	Tr.re	Fabaceae	WSD, Ru	Geo	ES, IT, M
	Paspalum distichum L.	Pa.ds	Poaceae	WSD, WP, (Hyg)	Geo	Pl
	Paspalum dilatatum Poir.	Pa. dl	Poaceae	Pl, WSD	Geo	Pl

Habitat: Wet Plain (WP, HYG), Wet Sand Dunes (WSD), Plains (Pl), Sand Dune (SD), Ruin (Ru). Life form: Geophytes (Geo), Phanerophytes (Pha), Hemicryptophytes (Hem), Therophytes (Thr). Distribution: Sub Cosmopolitan (SCOS), Euro-Siberian (ES), Irano-Turanian (IT), Mediterranean (M), Poly-realm (Pl).

3.2. Landcover Change Detection

To gain insight into the general trend of land cover changes, we conducted a classification of Landsat images for the years 2010 and 2020 within a 4000-hectare frame between the Ushmak stream and Sefidrud River (see Figure 2). The classification aimed to reveal changes in lagoons and the main vegetation groups, particularly groups 1 and 3. Figures 2 and 3 depict the detected land covers and their changes. We applied the Cross-tabulation function to overlay land cover maps, which revealed significant alterations in lagoon, grassland, and Rush–Rubus-type areas during this time. The grassland area decreased from 445 hectares in 2010 to 348 hectares in 2020 (reduced by 22%), while the area of the Rush–Rubus type doubled from 210 hectares to 407 hectares. This increase is equivalent to 46% (206 hectares) of the grassland area shifted to the Rush–Rubus type during this time (see Figure 3). The lagoon area, originally spanning 626 hectares, underwent a 29% decrease in 2020. Of this reduction, 15.4% was repurposed as farming land, 13.5% transitioned to grassland, and only 61% (380 hectares) remained unaltered. Nevertheless, due to the transfer of land from other categories, the lagoon area expanded to 447 hectares in 2020 (see Figure 3). The extent of farming land use increased from 1133 hectares to 1256 hectares (11% increase) in 2020. Additionally, some of the tree-orchard area was transferred to farming (39.6%) and the urban-rural class (12%), but it reduced by 20% in total. The area of urban and rural lands decreased by 8%, and sand bare land decreased by 5% during these times (Figure 3).

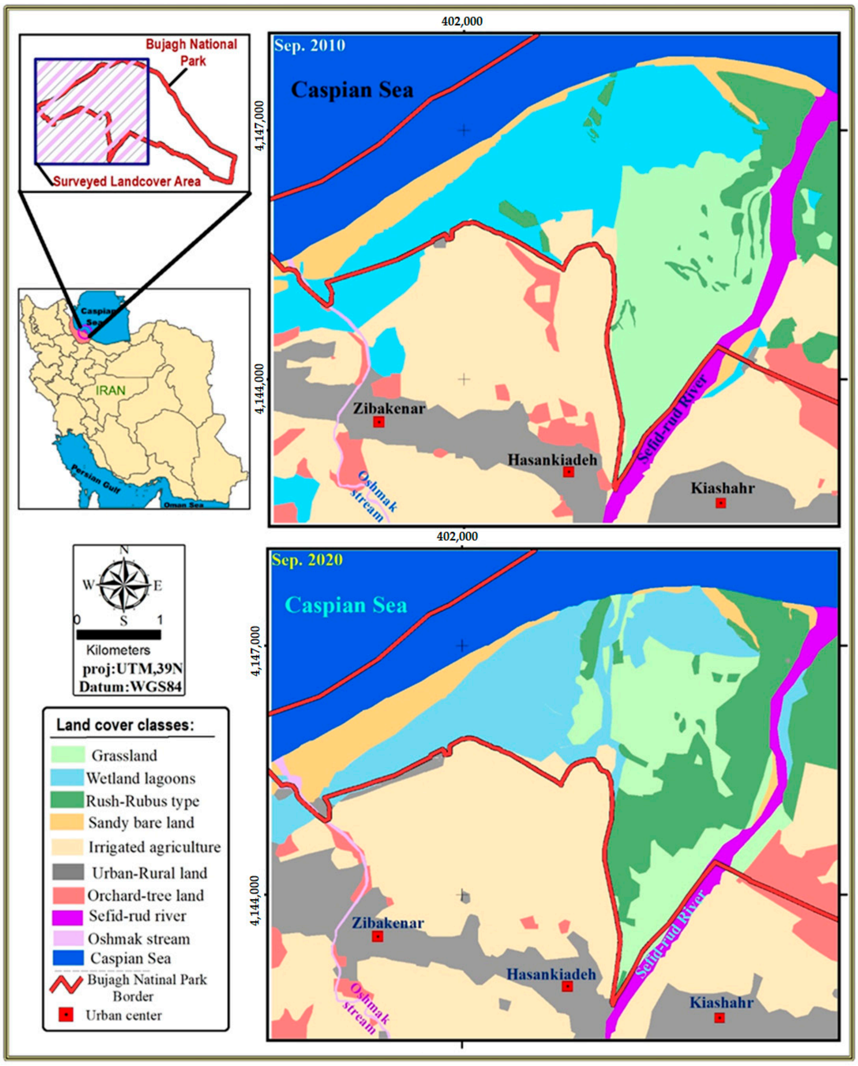
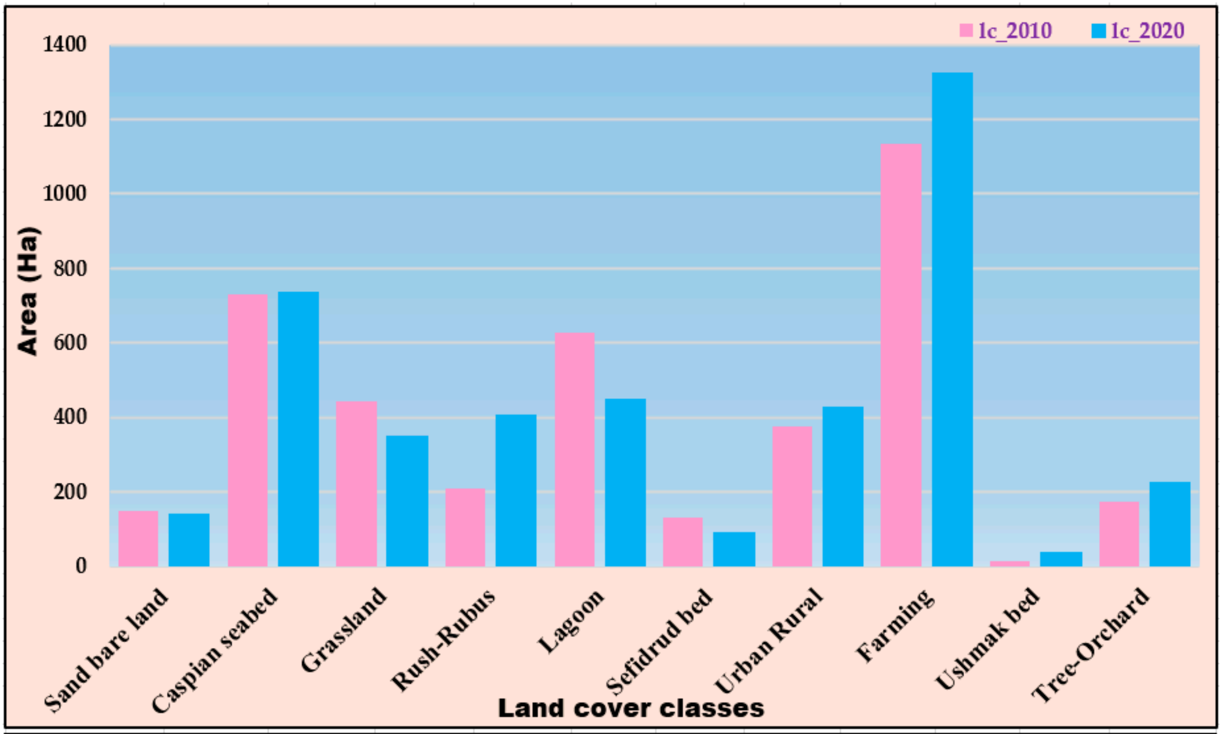


Figure 2. Land cover map of the study area in the time years 2010 and 2020.

3.3. Ordination Analyses

The gradient length of the dominant species matrix (13 species × 33 samples) was calculated to range from 2.9 to 3.5. This suggests that both linear and non-linear analytical methods could be effectively used. Unconstrained ordination methods, including DCA, NMDS, and PCA, were compared based on species distribution pattern and data compatibility, and then appropriate methods were selected. The results showed that three ordination methods demonstrated a significant relationship between species and edaphic variables at the 99% confidence level (Table 4). To select the appropriate analytical method, we considered the maximum compatibility correlation and minimum rotation errors (residual squares) between corresponding points in the two matrices. As a result, the NMDS analysis of matching species and edaphic variables matrices showed the lowest stress coefficient (S = 0.107; Figure 4), the lowest residual value (SS = 0.63), and the strongest correlation coefficient (r = 0.61). However, the compatibility of dominant species with soil heavy metals in NMDS, DCA, and PCA showed a high error (SS = 0.84) and a low compatibility rate and correlation coefficient (r) compared with the results obtained from the soil chemicals concordance (Table 4). Therefore, we decided to discontinue the analytical process of species versus heavy metals due to their weak influence on species distribution.



Land cover area(m^2)	Sand Bare land	Caspian seabed	Grassland	Rush-Rubus	Lagoon	Sefidrud riv. bed	Urban-Rural	Farming	Ushmak riv. bed	Tree-Orchard	Total area 2010
Sand bare land	797,500	354,375	52,500	5000	183,750	13,125	8750	66,875	20,000	0	1,501,875
Caspian seabed	439,375	6,849,375	0	0	4375	625	0	0	21,875	0	7,315,625
Grassland	0	0	2,286,250	2,055,625	51,875	38,750	0	17,500	0	0	4,450,000
Rush-Rubus	56,875	31,875	3750	1,627,500	110,625	11,875	2500	82,500	0	177,500	2,105,000
Lagoon	56,250	108,125	843,125	208,125	3,801,875	0	128,750	966,875	11,250	135,625	6,260,000
Sefidrud riv. bed	71,875	2500	131,250	51,875	138,125	833,125	17,500	66,875	0	0	1,313,125
Urban-Rural	0	0	0	0	3750	0	3,200,625	518,125	0	30,625	3,753,125
Farming	0	0	167,500	115,000	176,875	8125	500,625	10,146,875	2500	211,250	11,328,750
Ushmak riv. bed	0	0	0	0	1875	0	3750	1250	151,875	625	159,375
Tree-Orchard	0	0	0	0	0	0	206,875	693,125	3125	846,250	1,749,375
Total area 2020	1,421,875	7,346,250	3,484,375	4,063,125	4,473,125	905,625	4,069,375	12,560,000	210,625	1,401,875	40,000,000

Figure 3. Trend of land cover changes and shifted area in two time years, 2010 and 2020, in the study area (lc_2010 and lc_2020: abbreviations of land cover maps; blue cell: total area of each class in 2010; green cell: total area of each class in 2020; black number: shifted area to other classes in 2020; red number: unaltered area of each class between 2010 and 2020).

Table 4. Results of comparing NMDS, DCA, and PCA ordinations based on the Procrustean error test.

Ordinations	Sum of Residual Squares (SS)	Correlation Coefficient (r)	*p*-Value	Permutation Test
NMDS versus PCA-G1	0.634	0.605	0.001	999
NMDS versus PCA-G2	0.840	0.406	0.009	999
DCA versus PCA-G1	0.665	0.578	0.001	999
DCA versus PCA-G2	0.846	0.392	0.010	999
PCA-Sp versus PCA-G1	0.706	0.543	0.001	999
PCA-Sp versus PCA-G2	0.919	0.284	0.143	999

G1: soil chemicals group; G2: heavy metals group; Sp: species; SS: sum of squared differences between species ordination and rotated PCA-G1 or G2 matrices.

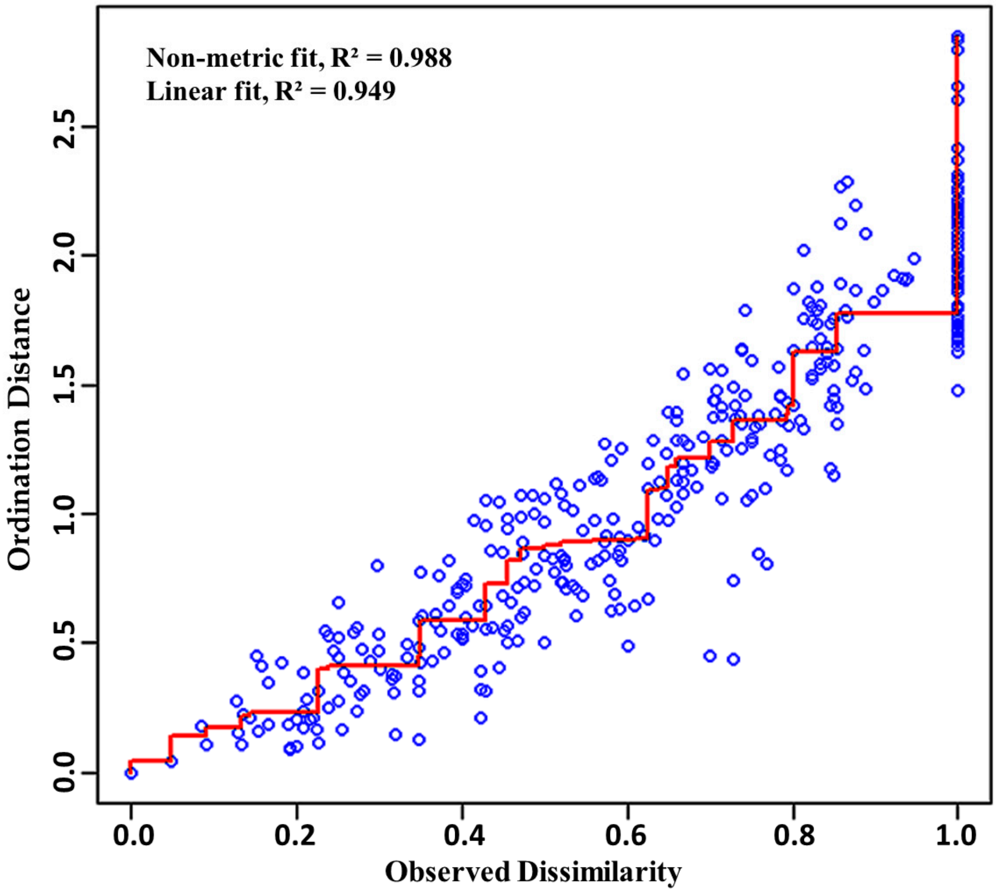


Figure 4. Shepard plot display compatibility and goodness of fit by using NMDS ordination. blue circle: denote observed dissimilarity between samples distance; red line: is a linear fit on basis squared correlation between fitted values and NMDS distances.

In the subsequent step, we analyzed the relationship between dominant species and soil chemicals based on NMDS components. As shown in Table 5, holly bramble and spiny rush in group 1 exhibited the longest gradient and significant correlation in the structure of NMDS axes (R^2 = 0.75, 0.78; p-value < 0.001). However, no correlation was observed between these species and the slope of changes in the soil chemicals matrix (Figure 5). Non-edaphic variables or anthropogenic factors may have contributed to the gradual dominance of these plants in the grassland territory. The sea rush (*J. maritimus*) from this group showed co-linearity with high sodium concentration, but the correlation between that and NMDS axes shows low significance (R^2 = 0.20; p-value < 0.02). The dominant plants of group 2 made a weak contribution to the structure of the plant community based on NMDS components (Table 5), except for Bermuda grass (*C. dactylon*), which had co-linearity with low-to-medium levels of sodium (Na), electrical conductivity (EC), and clay texture (Clay). The main species of group 3 have notable compatibility with the NMDS2 axis (R^2 = 0.63–0.75; p-value < 0.001), and two common clover species (*T. repens*, *T. fragiferum*) had a significant correlation with extreme levels of soil organic matter (SOM), total nitrogen (N), and bicarbonate (HCO_3), while dallisgrass (*P. dilatatum*) contributed in low-to-moderate levels of these factors. The common knotgrass (*P. distichum*) played a key role in the formation of the plant community (R^2 = 0.75; p-value < 0.001) and had a high correlation with medium to high levels of potassium (K), electrical conductivity (EC), and clay texture (Clay). Figure 5 shows the variation coincidence of plant groups and their dominant species with the soil chemicals and their changes on the NMDS axes; note that the weighted factors are merely drawn based on confidence degree at a p-value of less than 0.05 in Figure 5.

Table 5. Variation coincidence and correlation rate between dominant species and edaphic factors across NDMS axes. (Significance degree of dependence: '***', very high; '**', high:, '*'; moderate, '.' low; ' ', insignificance).

Plant Group	Species	NMDS 1	NMDS 2	Correlation Coefficient (R^2)	Confidence Level (Pr > r)
diagnostic, dominant species in plant groups	*C. dactylon*	−0.85	0.53	0.03	0.61
	E. caeruleum	0.96	−0.28	0	0.93
	E. granulata	0.28	0.96	0.04	0.54
	E. helioscopi	0.12	0.99	0.08	0.28
	J. acutus	0.96	0.27	0.75	*** 0.001
	J. maritimus	0.3	0.95	0.2	* 0.017
	P. dilatatum	−0.15	−0.99	0.73	*** 0.001
	P. distichum	−0.088	0.47	0.75	*** 0.001
	P. glaucum	0.68	0.73	0.06	0.44
	P. lanceolata	0.02	0.99	0.01	0.89
	R. sanctus	0.99	0.14	0.78	*** 0.001
	T. fragiferum	−0.21	−0.98	0.63	*** 0.001
	T. repens	−0.21	−0.98	0.73	*** 0.001
Soil chemicals and moisture	Electrical Conductivity (EC)	−0.51	0.86	0.36	** 0.002
	Bicarbonate (HCO_3)	−0.38	−0.93	0.36	
	Clay texture (Clay)	−0.75	0.67	0.35	** 0.002
	Sandy texture (Sand)	0.84	−0.54	0.06	0.39
	Silty texture (Silt)	0.63	−0.78	0.08	0.31
	Potassium (K)	−0.98	0.21	0.45	*** 0.001
	Sodium (Na)	−0.3	0.95	0.5	*** 0.001
	Solid Organic Matter (SOM)	−0.7	−0.72	0.42	** 0.002
	Total Nitrogen (N)	−0.56	−0.83	0.48	** 0.003
	Distance to ponds (Moist)	0.56	−0.83	0.17	. 0.07

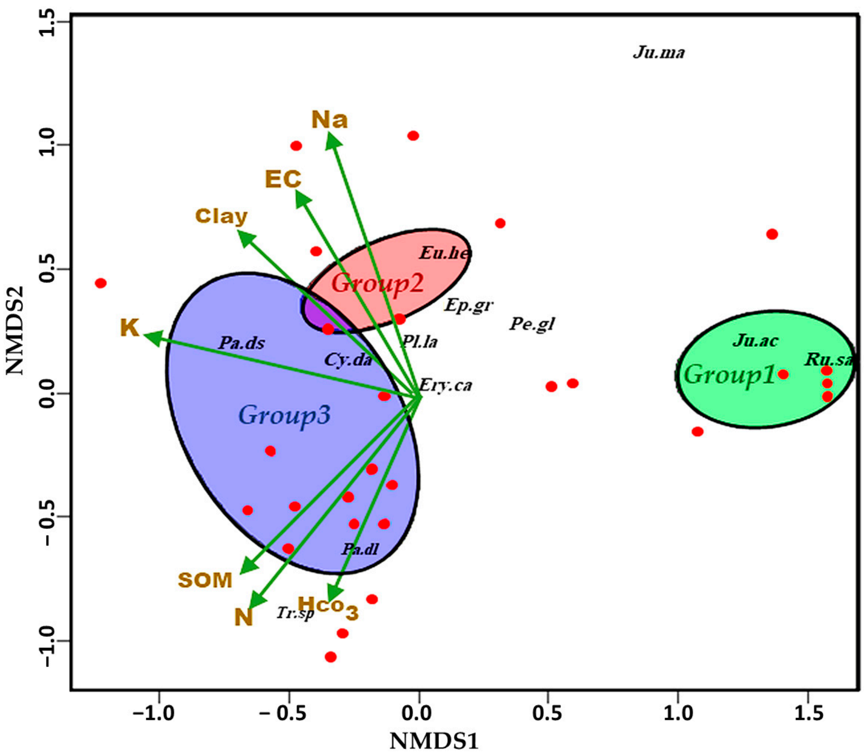


Figure 5. Illustrates the co-linearity between plant groups and dominant species with significant soil chemicals on NMDS components, with a confidence level set at p-value < 0.05. The red circle represents the sample plots, while the black letters correspond to the abbreviations of the dominant species (please refer to Table 3 for more information).

4. Discussion

The dominant plants in groups 2 and 3 exhibited inclinations towards certain soil chemicals, while group 1 did not display any relationship with them. Consequently, the role of soil elements and heavy metals was insignificant in the prevalence of Rush–Rubus shrubs despite their significance in the NDMS1 structure. Group 2 remained on a mild gradient of salinity (Na, EC) along the NDMS2 axis, whereas group 3 showed more flexibility to variations in element levels, clay texture, and soil exchange capacity, ranging from mild to high gradients. In the current study, the effects of soil heavy metals on the plant community (existing in farming drainage discharged into the wetland) were initially assessed, but no relationship was observed between the decrease in grassland extent and the dominance of Rush–Rubus shrubs. In the subsequent phase, the relationship between soil chemicals and the dominant plants of group 3 revealed significant evolutionary interactions among species. In other words, the alien plants, dallisgrass, and knotgrass (*P. distichum* and *P. dilatatum*) played a significant role in displacing endemic herbaceous plants and in situ epidemic of exotic grasses in the study area, as described by the CABI Compendium [57]. These alien species have widely replaced native and bird-feeding species, such as white clover (*T. repens*) and strawberry clover (*T. fragiferum*).

The widespread expansion of Rush–Rubus patches may be attributed to several factors, including the influence of the deep retreating of the soil water table and reducing waterlogging periods [58–61]. As soil water level gradually decreases in grassland, opportunistic species such as Rush–Rubus shrubs may establish and exhibit a range of physiological tolerance to drought beside of their advantageous reproductive capabilities. This expansion is influenced by both natural and anthropogenic factors. Natural factors include the lack of grazing on Rush–Rubus leaves by livestock, prolific seed and seedling production, prolonged seed viability in soil and water, and the rapid dispersal of lightweight seeds by water. Anthropogenic factors, including livestock, rural activities, and vehicle traffic, can help indirectly to plant proliferation. Asexual reproduction of these plants also contributes to the effective propagation of these species; in fact, owning underground stems and rhizomes facilitates the rapid growth and proliferation of them (see [62–67]).

The wide natural grasslands play a crucial role in supporting birds during foraging, as the presence of wintering geese along migration routes heavily depends on the habitat situation. The quality of forage beds is contingent upon the availability of dietary herbs within the habitats that host wintering geese. These birds must provide a significant portion of their food supply, and some should be reserved for reproduction time during the spring season [61,68,69]. According to Zou et al., [70], small and large white-fronted geese in similar areas are sensitive to changes in food resources. The change in bird abundance is influenced by the flowering time and the durable survival of sedges in natural grassland. The early seasonal lowering of the soil water level can cause the plant to wither and become unsuitable for feeding during winter.

Another study (Zhao et al., [59]) confirmed that the contraction of wet meadows in the East Dongting wetland in China was the main reason for the reduction in the wintering bird population, particularly the great white-fronted goose. This event occurred due to the early retreat of the water soil level in the wet meadow. Similarly, in Bujagh National Park, the decreased presence of wintering geese can be attributed to the early seasonal retreat of the soil water level in late summer, which diminishes the water sources feeding the wetland, leading to early drying up in forage sites. The findings of Guan et al., (2016) showed that the optimal timing for the water level regression in meadows should be from the beginning to the middle of October. Under this situation, forage food quality would remain favorable for geese in winter. Another study (Lei et al., [61]) showed that wintering geese in the Yangtze region in China rely on the suitable quality of food in meadows during the migration season. Geese usually react to stress caused by undesirable feed sources by increasing their foraging range, but this reaction cannot lead to a change in their wider trophic niche. The flexibility of bird behavior may not guarantee its survival in confrontation with environmental adversities. Accordingly, Lei et al., [61] suggested that the maintenance of natural hydrological regimes in the grasslands, especially from late September to November, could guarantee an essential food supply for the goose population in winter.

The results of the land cover analysis indicated a reduction in the size of lagoons and grassland boundaries and an increase in the spread of the Rush–Rubus type between 2010 and 2020. Our findings of field data suggested that the decline of Sefidrud watering, diversion of feeding streams, and reduction in groundwater level could be influenced by the drying of grasslands and shrubs. According to the report on water management in the Sefidrud catchment, the 35-year long-term average discharge of the entrance station to the national park is 115 m^3/s, while the average discharge of this station has currently decreased to less than 50 m^3/s in the last decade. Despite the ongoing decrease in Sefidrud flow towards the wetland, the Ushmak stream, a farming drainage canal, is known as the main feeder of the wetland and its satellite grasslands (on a smaller scale than Sefidrud). However, some branches of the Ushmak stream have been recently diverted towards the sea by an earthen dam structured for land exploitation, which means that the natural flow of the wetland cannot be supplied in the current situation. Overall, all the aforementioned reasons could potentially reduce the extent of grasslands and birds forage grounds. Therefore, it is firstly essential to pursue water rights and sustainably maintain the environmental flow in the Bujagh wetland, especially in the summer and autumn seasons. In the second priority, returning diverted streams into traditional routes towards lagoons and removing the blockage of the feeding streams through alternative canals can probably matter in the wetland restoration.

5. Conclusions

In the final summary, the decline in the wintering geese populations in the Bujagh grasslands may be influenced by various factors, including changes in the wetland's hydrological patterns at a basin scale and human-induced threats within the national park at a habitat scale. As a result, it is crucial to implement measures such as controlling livestock density, restricting grazing to the buffer zone, and organizing rural activities. These management actions can be achieved by designating specific zones for human activities and limiting access to birds forage areas, which have been overlooked in national park management. Additionally, establishing regulations and oversight on recreational and rural activities, particularly vehicular traffic, is an essential strategy for mitigating adverse changes in the grassland ecosystems and rejuvenating the presence of migratory birds. This approach will ensure safe habitats and sufficient trophic resources for the revitalization of the geese populations.

Author Contributions: Methodology, M.M. and M.K.; Data curation, M.M.; Resources, M.M. and M.K.; Formal analysis, M.M.; Software, M.M. and M.K.; Investigation, M.M.; Visualization, M.M. Writing—original draft preparation, M.M.; Conceptualization, M.M. and M.K; Project administration, A.H.H.; Supervision, A.H.H.; Writing—review & editing, M.M.; A.H.H. and M.K.; Validation, M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data are available upon request to the authors.

Acknowledgments: We would like to express our sincere appreciation to our esteemed colleagues: Mahmood Soofi, Department of Conservation Biology, University of Gottingen, Germany; Soghra Ramzi and Saeideh Tamjidi, University of Guilan (Iran). Their invaluable contributions were instrumental in fulfilling the sampling design and botany sections in this research.

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

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