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Rangeland Management and Ecological Adaptation Analysis Model for *Astragalus curvirostris* Boiss

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Abstract: The present study investigates the ecological requirements of *Astragalus curvirostris* Boiss, with emphasis on determining the ecological factors that affect the distribution of plant species, and the species' response to changes in ecological factors using a Generalized Additive Model (GAM) in the Iranian Province of Zanjan from 2017 to 2019. Randomized-systematic sampling was used to collect vegetation data. Data analysis was performed using SPSS17 and CANOC4.5 software. The results showed that the growth and development of *A. curvirostris* change according to environmental factors linked to the composition of the soil and the variety of the other species present. This model is indicative of a competitive limitation along the environmental gradient. By understanding all environmental parameters, the necessary steps could be taken towards planning proper management programs, including rangeland grazing management and determining the proper moment for seed collection, which will result in the conservation, improvement, and restoration of rangelands.

Keywords: *Astragalus curvirostris* Boiss; species distribution; ecological factors; generalized additive models

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1. Introduction

Prediction models for plant species distribution have a prominent role in monitoring, evaluation, restoration, conservation, and expansion of rangeland ecosystems. These models are considered potential tools to understand species distribution and habitat suitability for plant species [1]. Investigating the response curve of plant species to environmental gradients and determining which method and model are most successful in understanding the ecological range and optimum conditions for that plant species in an ecological niche, is one of the main issues of rangeland ecology [2–4].

Researchers are developing statistical and mathematical models to detect and predict the geographic distribution of species at a different spatial scale, based on bioclimatic environment data [5]. Various methods have been introduced for investigating the relationship between the distribution of different plant species and environmental factors [6–9].

The most important models include GLM (Generalized Linear Models), GAM (Generalized Additive Models), ANNs (Artificial Neural Networks), PCA (Principal Components Analysis), and CCA (Canonical Correspondence Analysis) [10–13]. Some models such as GLM and GAM are used to determine the likeliness of species presence, and others such as CCA, ANNS, and PCA are used to examine the factors affecting species distribution and the spatial prediction of the habitat suitable for the establishment of the target species [14,15]. CCA and GAM are among the methods most used for analyzing the reaction of plant species to environmental factors [3,16].

Abbassian and colleagues [17] used a GAM model to investigate the response of *Bromus tomentellus* and *Achillea millefolium* to environmental gradients. The sand content of the soil is a parameter that has a positive effect on *B. tomentellus* distribution, whereas this variable negatively affects the presence of *A. millefolium*. Alavi and colleagues [18] also investigated the reaction of beech to environmental variables using a generalized additive model. They concluded that if the goal of the study, in addition to the shape of the response curve, is also to estimate characteristics such as the ecological optimum and range of the environmental variable for a species, then applying the generalized additive model individually for each of the environmental variables would be a better option for expressing the species' reaction to these variables. The predictive modeling of plant species distribution is defined based on the relationship between the data of species presence and environmental variables. In these models, the likeliness of plant species occurrence is predictable from the spatial distribution of environmental variables.

A. curvirostris (Figure 1) is a member of the Fabaceae family. It is a perennial, herbaceous plant with a height of 5–40 cm. This species is endemic to the IranianTuranian region and is exclusive to Iran, and can be found in north, north-west, west, and central Iran [19]. Considering the importance of *A. curvirostris* in terms of its distribution level, forage production, suitable palatability, as well as the species' role in soil conservation, the present study was conducted to identify the ecological needs of *A. curvirostris*. The resulting data can be used to design programs for the management and restoration of the country's rangelands, investigate the species' response to changes in environmental factors, determine the potential of the target species in specific ecological conditions, and provide a better understanding of its ecological niche.

Figure 1. Astragalus curvirostris Boiss.

2. Materials and Methods

2.1. Geographic Position and Characteristics of the Studied Area

The studied was carried out in a 5072 hectare area, 30 kilometers north-east of Zanjan Province in Iran, latitude 36°54′20′′ to 36°56′25′′ north and longitude 48°25′18′′ to 48°32′22′′ east (Figure 2).

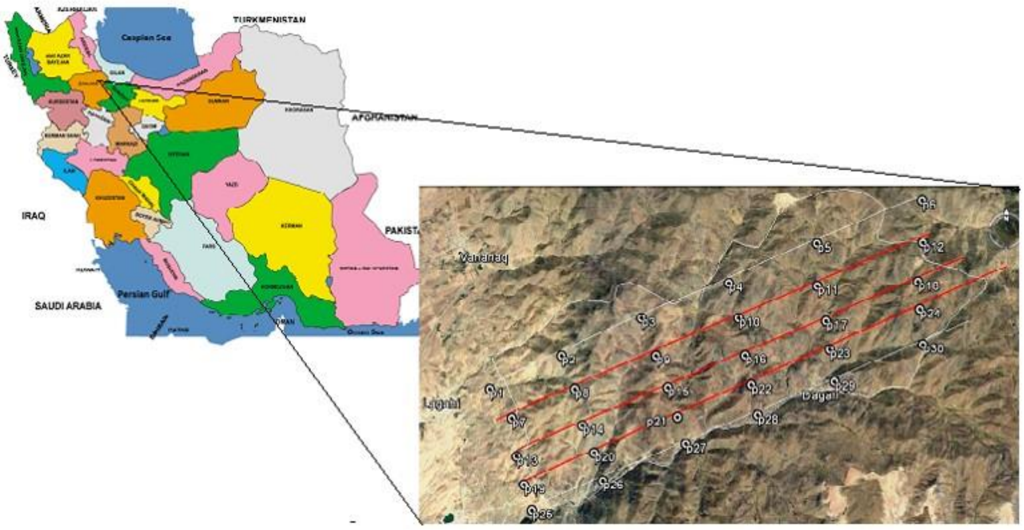

Figure 2. Location of the study area and distribution of sample units.

2.2. Habitat Characteristics of the Studied Area

The habitat of the target species is mountainous with rocky exposure and where soil depth can vary from 40 cm to over one meter. The area is part of the Karaj geological formation with a combination of tuff, gray-colored tuff sandstone, siltstone, and lichen-layered tuff.

The sea level elevation of the distribution latitude of this plant ranges from 2000 to 2700 m. The electrical conductivity, soil acidity, lime, organic carbon, and nitrogen values were 0.24–0.65 ds/m, 6.63–7.99, 1.60–11%, 0.24–1.94%, and 0.04–0.33%, respectively, with a loam-sand soil texture. The region's climate, based on the Modarres and Sarhadi climatic classification method [20], is cold semi-arid with an average annual precipitation of the studied area of 330.1 mm and a mean temperature of 7.5 °C.

2.3. Methodology

Recognizing the resources and flora, its habitats are a requisite for the systematic and proper use of that rangeland. Field practices regarding the collection and identification of the region's plant species were carried out from late-April to late-May/early-June of 2018. The plant species, present in the habitat, were collected, dried, and pressed. They were then identified using Flora Iranica [21], 1963–2001), Flora of Turkey [22], Colored flora of Iran [19], Flora of Iran [19], and Cormophytes of Iran [23].

Systematic sampling was used to collect vegetation data [24] from plots established along linear transects. Five equally distanced transects were used according to the environmental gradient. Then, six equally distanced plots were established on each transect. The resulting 30 plots were used in this ecological unit and the geographic position of each plot was recorded (Figure 2).

The transect length was determined in accordance with the habitat length and the distance from each other was determined in accordance with the habitat width. Using the species–area curve method [25], the plot size of each ecological unit was determined 2×2 m.

After establishing the sampling units on the transect, abundance, number of plants, canopy cover percentage, and growth of each studied species during the current year were measured. All parameters were measured during the flowering stage. Abundance was carried out by taking note of the presence of each species, the number of plants was carried out by counting, and their canopy cover was determined by measuring the percentage of area occupied by the plants in the graded plots. The growth of the studied species during the current year was measured via the cut and weigh method. Meanwhile, the percentage of total canopy cover, the percentage of stone and gravel, the percentage of bare soil, and the litter percentage in each plot were also measured. The target area was selected so that the studied species was observable along the environmental gradient, from the lower endurance level to the upper endurance level, while the plant was still able to carry on with its vital activities including survival, growth, and reproduction.

2.4. Data Collection of the Environmental Factors in the Distribution Location of the Studied Species

One soil sample from the plant's rooting depth (repeated three times) was collected from each plot (complex sample) in order to investigate the effect of environmental factors on the distribution of the studied species. The studied region is mountainous and the ground in most places was no deeper than 25–30 cm. Then, the sampling was performed from a depth of 0–30 cm. The soil texture (using the hydrometer method), acidity (using saturated soil and a pH-meter), percentage of Total neutralizing value (TNV) or the lime percentage, absorbable phosphorous, absorbable potassium, organic carbon content, total nitrogen content, and the soil saturated moisture of the soil samples were measured.

Thirty soil samples were also taken using a fixed-volume sampling cylinder (100 cm^3), which was used to measure the soil's apparent density. The soil in the cylinders was dried (24 h inside a 105° oven), weighed with a precise scale, and the apparent density was calculated via the following formula:

$$BD = W/V$$

where BD = Bulk density (gr/cm^3), W = Dry soli weight (gr), V = Cylinder volume (100 cm^3).

The geographic position of each plot (the latitude and longitude of the center of each plot) was recorded and topographic factors such as elevation from sea level, slope percentage, and geographic direction were specified for each plot. These data are important because they affect the amount of moisture available to the plant and affect the performance of the vegetation. The geographic direction variable was taken according to the four cardinal directions and four intermediate directions (90, 45, 135, 180, 225, 270, 315, and 360). Using the equation of Eichenberger [26] they were converted to quantitative data via the equation below:

$$A' = \text{Cos}\ (45 - A) + 1$$

where A = azimuth value, A′ = converted value of direction.

Annual average precipitation, monthly average precipitation, and annual mean temperature were determined using the existing meteorological data and the nearby meteorological stations.

2.5. Determining the Growth Stages of the Studied Species

During 2018 and 2019, the growth stages including the beginning and end of the vegetation stage, the beginning and end of the flowering stage, the beginning and end of the seed maturation stage, the seed shedding and drying out of the plant stage, and the dormancy and overwintering stages were recorded. This was done by installing a numbered plate adjacent to ten plants chosen from the habitat. The selected plants were similar in terms of height, basal area, number of flowering branches, and vigor. The data related to the species phenological stages were recorded at 15-day intervals during the vegetative stage and 7-day intervals during the reproductive stage [27] and was used to construct the plant's phenological diagram.

2.6. Data Analysis

First, the environmental data and the vegetation data were fed in the Excel software as two individual files. The columns relevant to each variable were analyzed using the Canoco 4.5 software.

2.7. Constructing the Response Curve of the Studied Plant Species to Environmental Factors

The generalized additive model was used to predict the plant species' (Target species) response to environmental changes [9,28–31]. The Akaike Information Criterion was used to rank the factors affecting species distributions [32].

3. Results

3.1. Identified Plant Species

The investigation and identification of the region's vegetation revealed 66 vascular plant species, belonging to 51 genera and 18 families. The most important families in terms of species abundance were Poaceae with 12 species (18.2%), Fabaceae with 10 species (15.2%), Asteraceae with 8 species (12.1%), Lamiaceae with 7 species (10.6%), Apiaceae with 7 species (10.6%), Caryophyllaceae with 6 species (9.1%), Liliaceae with 3 species (4.5%), and 13 sporadic species (19.7%) that belonged to other plant families (Figure 3).

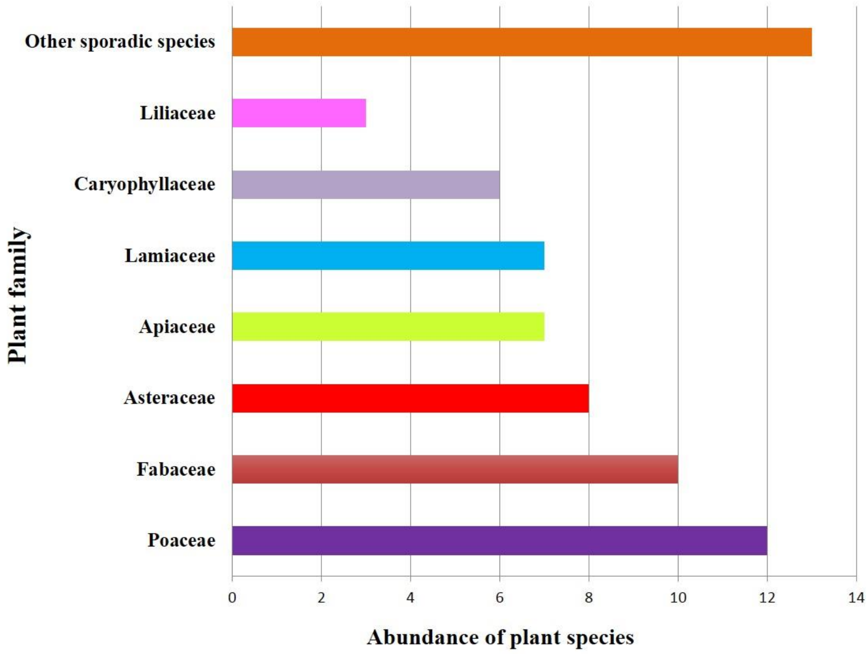

Figure 3. Abundance of different plant families in the areas studied.

In terms of life form, 66.7%, 15.1%, 10.6%, 6.1%, and 1.5% belong to hemicryptophytes, camphites, trophites, geophyte, and phanerophytes, respectively (Figure 4).

3.2. Vegetation Characteristics of the Studied Region

The species present in the study area of our interest were *Bromus tomentellus*, *Poa bulbosa* and *Astragalus* spp. The distribution of these species extends from 2000 to 2700 m. In particular, in the range from 2200 to 2400 m, their abundance is greater and reaches the maximum distribution around 2300 m. The average vegetation characteristics of the studied region are illustrated in Table 1.

Table 1. Characteristics of the vegetation in the *A. curvirostris* habitat.

Forage Production of Target Species (kg/ha)	Frequency of Target Species (%)	Density of Target Species (Ha)	Canopy Cover of Target Species (%)	Gravel and Stones on the Soil Surface (%)	Bare Soil (%)	Litter (%)	Total of Canopy Cover (%)
198	67	41,667	10	23	18	3.9	54.9

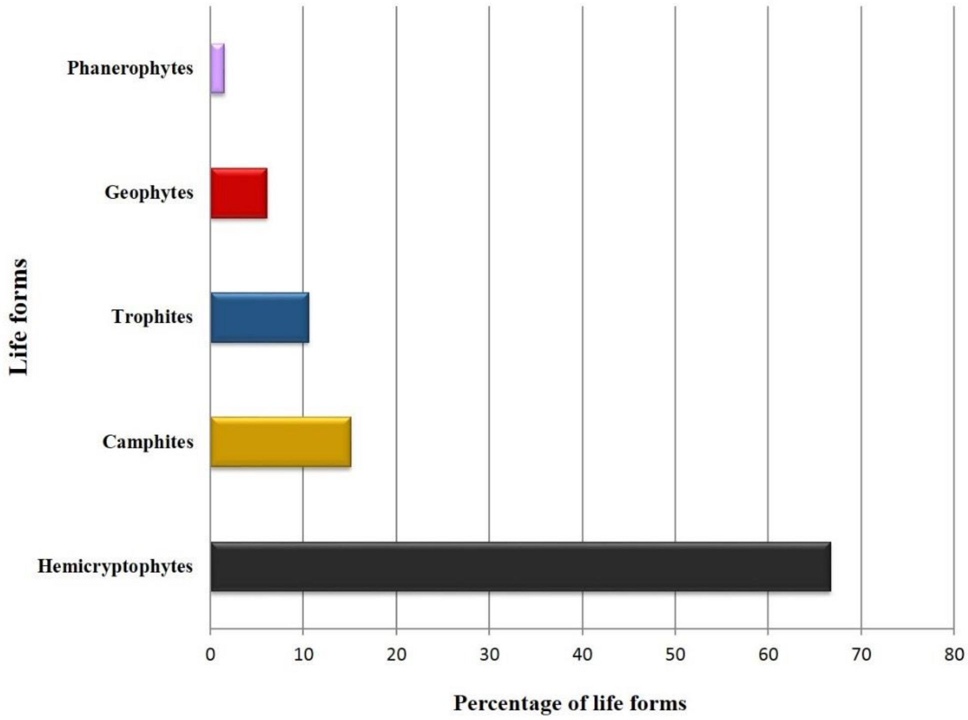

Figure 4. Abundance of plant forms (Rankier method) in the areas studied.

The plant density (number of plants per hectare) of the major (dominant) species of the studied species' habitat is illustrated in Figure 5. The canopy cover percentage of the major (dominant) species of the target species' habitat is depicted in Figure 6.

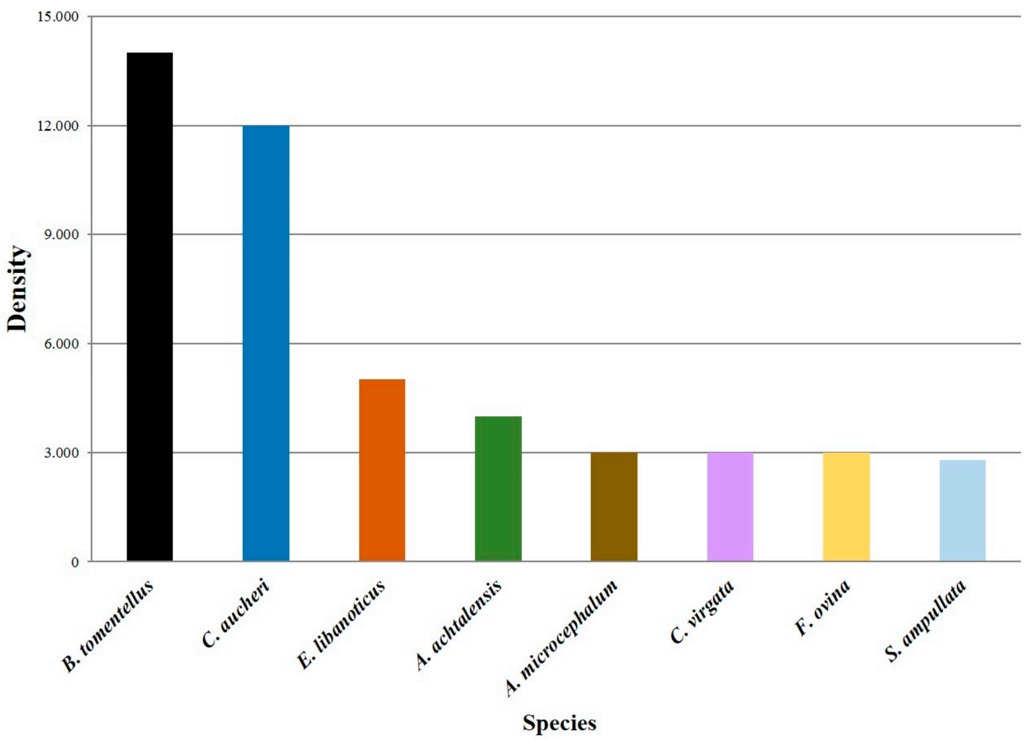

Figure 5. Density of the dominant species in the areas studied.

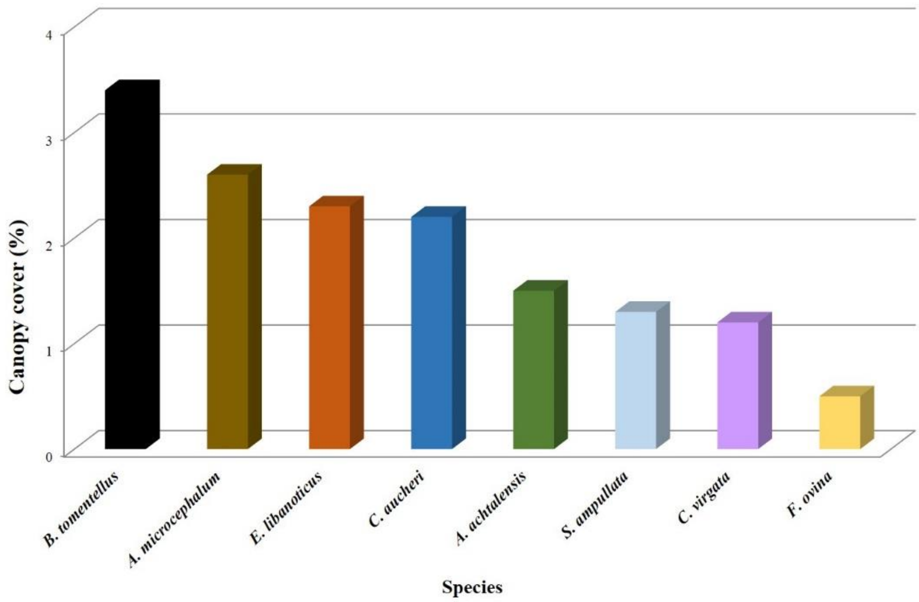

Figure 6. Canopy cover of dominant species in the areas studied.

3.3. Investigating the Ecological Requirements of A. curvirostris in the Studied Habitat

Applying the generalized additive model with the Poisson error distribution for each of the environmental variables showed that the saturated moisture percentage (SP), electrical conductivity (EC), acidity, total neutralizing value or lime percentage (TNV), soil bulk density (BD), clay percentage (Cl), sand percentage (Sa), silt percentage (Si), bare soil percentage (BS), percentage of stones and gravel on the soil surface (St), elevation from sea level (Al), and Aspect (As) significantly affected the distribution and productivity of studied species to the level of less than 0.01%. Litter percentage (Li), land slope percentage (Sl), and soil organic carbon percentage (OC) had a significant difference to the level of 5%. Variables affecting *A. curvirostris* distribution and productivity were ranked using the Akaike Information Criterion and are showed in Table 2. The studied species' response curve of *A. curvirostris* in correspondence to each of the effective environmental factors was investigated (Figures 7–9).

Table 2. The results of the generalized additive model for each of the significant explanatory variables.

Environmental Variables	F	P	AIC
OC (%)	3.03	0.05	390.3
SP (%)	13.78	0	212.22
EC (ds/m)	10.74	0	248.49
pH	10.9	0	376.35
TNV (%)	11.4	0	374.87
BD (gr/cm^3)	6.08	0	323
Cl (%)	8.05	0	273.87
Sa (%)	10.1	0	254.15
Si (%)	11.65	0	244.32
BS (%)	11.99	0	227.7
St (%)	5.32	0	333.42
Li (%)	3.74	0.02	367.13
Sl (%)	3.29	0.04	383.22
Al (m)	4.96	0	339.38
As (d)	23.8	0	336.82

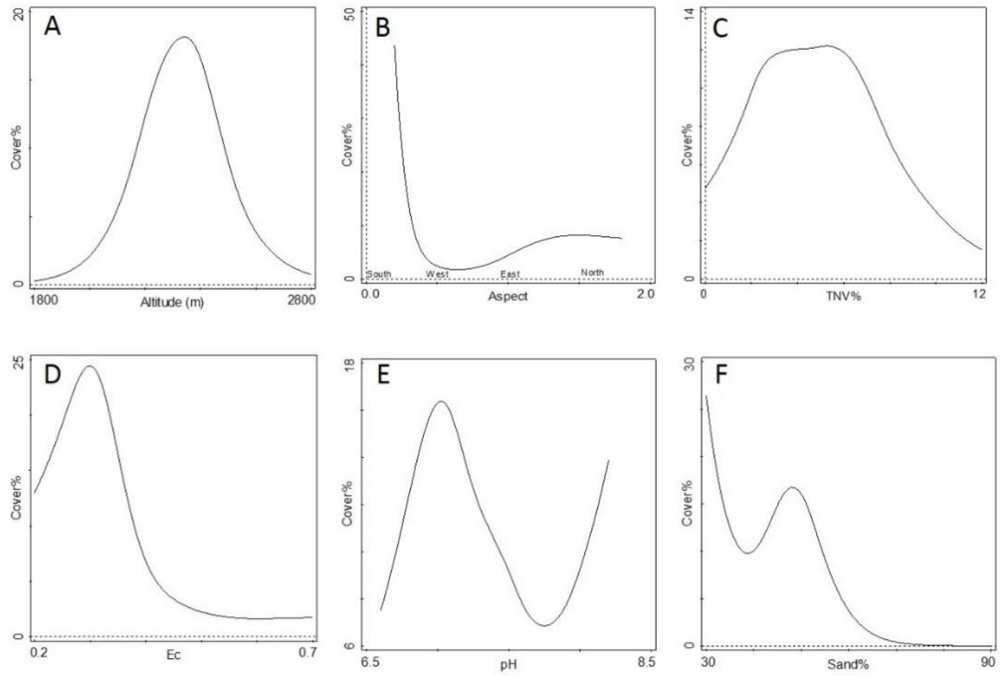

Figure 7. Species responses to different environment conditions. (**A**) altitude, (**B**) aspect, (**C**) total neutralizing value (TNV) or lime percentage, (**D**) electrical conductivity, (**E**) soil acidity, (**F**) sand.

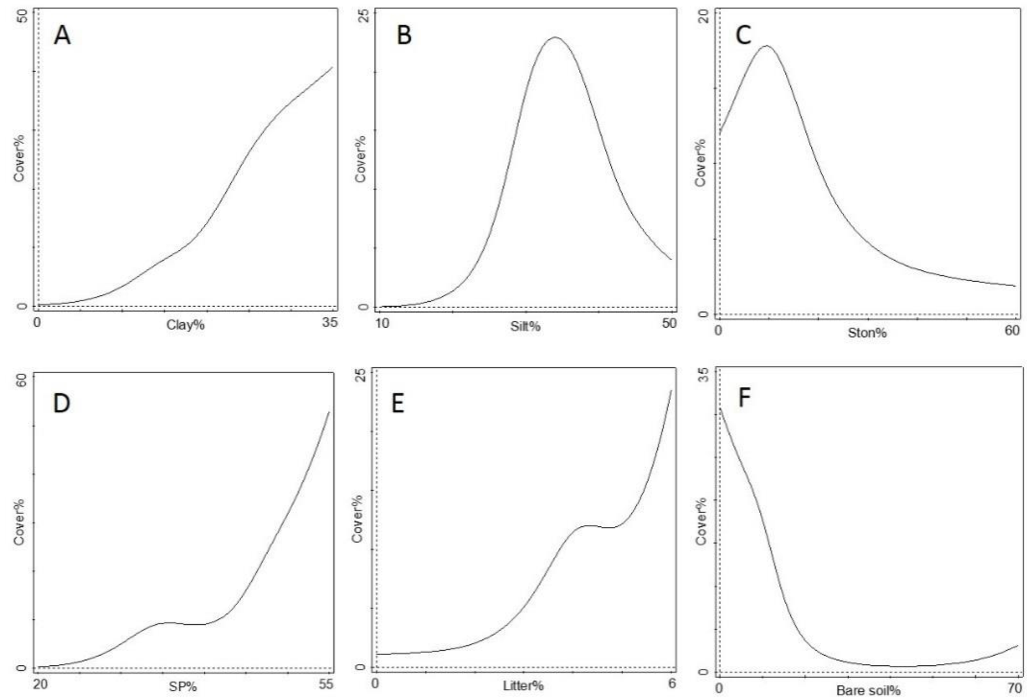

Figure 8. Species responses to different environment conditions. (**A**) clay, (**B**) silt, (**C**) stone and gravel, (**D**) saturated moisture percentage, (**E**) litter, (**F**) bare soil.

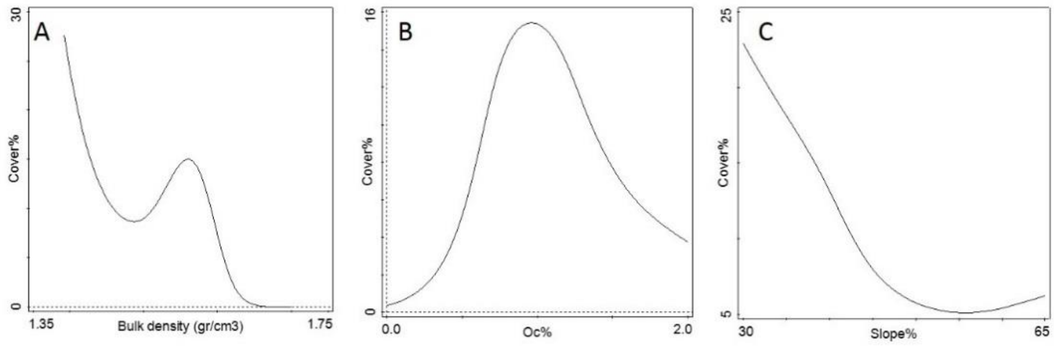

Figure 9. Species responses to different environment conditions. (**A**) bulk density, (**B**) organic carbon, (**C**) soil slope.

Studied species' distribution, associated with the elevation from sea level variable, showed that these species' response to altitude changes is unimodal. Increasing the elevation from sea level to 2300 m increased the species' canopy cover percentage, while further increase in elevation resulted in a declining trend of canopy cover percentage. The presence of these species in the studied area started at 2000 m and continued up to 2700 m above sea level but was not observed outside this altitude range (Figure 7A). The species showed different responses to changes in slope direction. The highest level of canopy cover was observed on the southern slope and the lower limit of these species' presence was observed on the western slope (Figure 7B).

Furthermore, increased slope leads to the steady decrease of the species' canopy cover percentage and soil slope higher than 50% results in an extreme reduction of distribution and species presence (Figure 9C). Maximum canopy cover was observed in soils with 2–6% lime content (Figure 7C). Increases in soil salinity up to 0.3 ds/m resulted in an increasing trend of canopy cover and further increases led to the reduction of canopy cover, while soil salinity above 0.5 ds/m resulted in a drastic reduction of canopy cover (Figure 7D).

The species' response to changes in soil acidity (pH) was bimodal. The increase of soil pH up to 7 results in increased canopy cover percentage, while increases in soil pH from 7 to 8 led to the reduction of canopy cover; however, further increases in pH increased the canopy cover percentage. The lower limit of the species' presence was observed at pH 7.6 (Figure 7E).

The species reaction to soil clay percentage, level of saturated moisture, and amount of litter on the soil surface followed a positive trend. Increasing these factors led to an increment in the canopy cover (Figure 8D,E). The response of the species was negative to increases to soil sand percentage, percentage of bare soil, and percentage of stone and pebble on the soil surface (Figures 8C and 9A). Increasing soil organic carbon percentage up to 1% resulted in an increase in the canopy cover percentage of the target species while further increases of this variable led to the reduction of canopy cover (Figure 9B).

3.4. Growth Stages of A. curvirostris in Zanjan Province

The results over two years, obtained from studying the phenology of *A. cuvirostris*, showed that the growth of the species begins in the last 10 days of March when the weather gradually becomes warmer, and its vegetative growth accelerates from mid-April with the increase of environment temperature. Initial flowering usually begins in the last ten days of April and continues for thirty days (up to the last 10 days of May). Seed formation begins from 22 May, and the seed maturing stage continues up to the last 10 days of June, based on the duration of the flowering stage. Seed shedding usually begins from the end of June and continues up to late July. The plant's vegetative cycle reaches its minimum in late July and enters the overwintering stage (Figure 10).

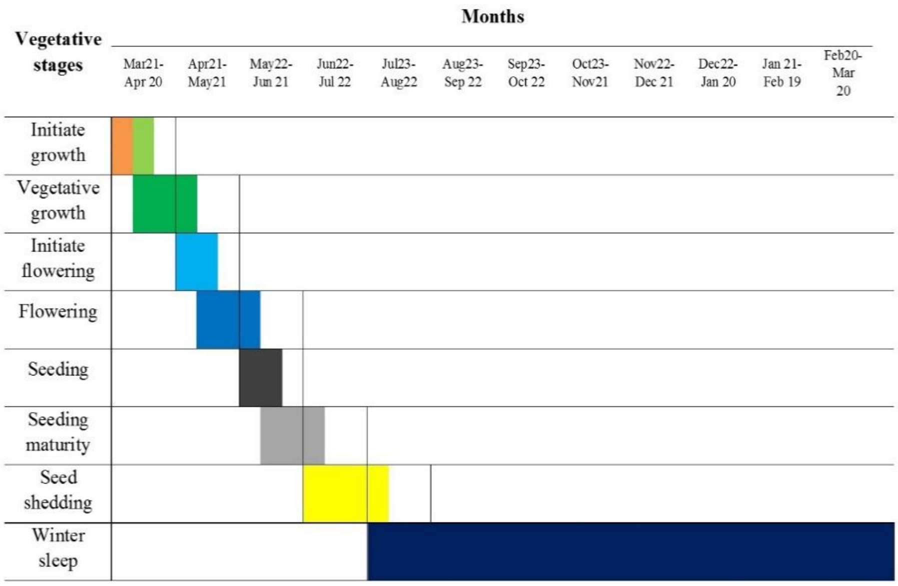

Figure 10. Phenological stages of *Astragalus curvirostris* Boiss in the areas studied.

4. Discussion

From a rangeland management point of view, plants with forage, medicinal, industrial, and protective value are of great importance [33–39]. These species are adapted to their environmental conditions and, with wise management, can be utilized in a supported environment [40]. On the other hand, the proper, efficient management of every region relies on accurate knowledge of the quantitative and qualitative characteristics of the region's flora. Introducing the vegetative elements of a region is especially important in determining and properly using its vegetative potentials [41].

Studying the vegetation revealed that 54.6% of the species present in the *A. curvirostris* habitat belong to the Poaceae, Fabaceae, Lamiaceae, and Apiaceae families [42–45]. This indicates the relatively high potential of the studied habitat for the production of forage and medicinal plants. The Poaceae, Apiaceae, and Fabaceae families produce forage plants for livestock consumption and play a role in soil and water conservation in rangelands. The Lamiaceae family produces medicinal plants, while the Fabaceae family plays a role in soil fertility through the process of nitrogen biofixation, thus having a special place in rangelands and pastures [46]. The Asteraceae family accounts for approximately 12.1% of the studied habitat's vegetative elements. It appears that the abundance of certain species of this family in the studied habitat is indicative of destructive human activities. However, the members of this family are well adapted to the region's climatic conditions (part of the Iranian-Turanian region) and usually increase in highly devastated regions [47]. By investigating the life form of the species, present in the habitat, it became evident that hemicryptophytes are the dominant vegetative form, camphites rank second, and trophites are in third place. Hemicryptophytes being the dominant life form indicates the compatibility of these life forms with the climate of the studied habitat (a cold and mountainous climate) [48]. Camphites rank second in terms of the number of species. Camphite life forms are usually more tolerant against drought and livestock grazing [27], which could be one of the reasons for these plants' dominance in the studied region. Recent droughts and the short growing season probably had an effect on trophite abundance. The excessive exploitation and factors such as human interference are among the reasons for the reduction in perennial plant abundance with the increase in opportunity for the development of annual plants [49].

The productivity of the studied species, associated with the elevation from sea level variable, showed that that the species' response follows a unimodal model. The presence of these species began from 2000 m in the studied region and continued up to 2700 m above sea level and was not observed outside this latitude range. The highest level of canopy cover was observed in the southern direction and the lower limit of these species' presence was observed in the western direction. Geographical direction plays an important role in plant distribution and on the amount of light, water, and nutrients available [50]. Since the southern directions are more affected by light and have more evapotranspiration, it can be said that this species is a heliophyte and drought-resistant plant. Furthermore, increased slope led to the steady decrease of the species' percentage of canopy cover, where slopes higher than 50% resulted in an extreme limitation of canopy cover and species presence (the species' response followed a monotonic decrease model). In steep lands, the possibility of water infiltration is low, and soil formation is slower in the long run; therefore, the conditions for the establishment of these species are not provided, a topic that Harris (2002) also mentioned. Therefore, terrain and climate-related factors are influential on the distribution of the studied species, which is consistent with the findings of previous researchers [48,51–55].

On the other hand, results showed that the studied species had maximum canopy cover in soil with a 2–6% lime content (the species' response followed a unimodal model). Lime increases soil alkalinity and provide a source of calcium and magnesium for the plants, while also increasing water retention in the soil. The sum of these factors is influential on the distribution and presence of the species in the regions [56,57]. Despite the fact that soil salinity is not an issue in mountainous rangelands, it was observed that its increase up to 0.3 ds/m resulted in an increasing trend of the species' canopy cover, while salinities over 0.5 ds/m resulted in a drastic reduction of canopy cover. According to the study's results, the species' response to soil pH was combinational. Therefore, increasing soil pH up to 7 results in an increased percentage of canopy cover, while increasing soil pH from 7 to 8 leads to the reduction of canopy cover, and increases in soil pH above 8 result in further growth of the canopy cover percentage. The lower limit of the species' presence was observed at a soil acidity of 7.6. Soil acidity affected plant growth, directly or indirectly, and its most important role was controlling the solubility of nutrients in the soil. In other words, nutrient absorbability is largely dependent on this factor. Nutrients show different levels of solubility at various pH levels, which could therefore be deemed a factor in the distribution of species in the region. In this regard, Chaplygin and colleagues [51] also introduced electrical conductivity and soil pH as factors that influence the distribution of *Artemisia fragrans* and *Artemisia austrica* in the studied regions. The species responded differently to soil texture. These species showed better compatibility in clay-loam soils, compared to sand-loam soils. Maximum species productivity and presence were observed in soils with a clay-loam texture and minimum presence was observed in sand-loam soils. The species' response to the moisture saturation level and the amount of leaf litter on the soil surface showed a positive trend. The species' canopy cover grew with increases in these factors but the response to an increase of stones and pebbles on the soil surface, as well as the percentage of bare soil, showed a negative. This confirms the importance of soil moisture and texture on the distribution and presence of the species in the studied habitat. In addition to impacting nutrient absorption, permeability, and ventilation, soil texture also affects the level of moisture available to plants and plays an important role in the distribution of various species [58,59]. The optimum value for species productivity was observed in areas where the soil's organic carbon percentage fell in the 0.8–1.2% range. In this regard, Chesworth [60] believes that improving the soil's organic carbon content increases crop production and restores the soil and biomes.

One of the major issues of Iran's rangelands is the lack of attention to the phenological stages of plant species that leads to the improper and premature exploitation of the natural forage of rangelands. By recognizing and understanding the phenological stages of dominant and key species, the necessary steps could be taken towards planning proper management programs, including rangeland grazing management and determining the proper moment for seed collection, which will result in the conservation, improvement, and restoration of rangelands. According to the results obtained from this study and other's [61–63], the phenological stages of the target species and the accompanying dominant species, as well as the soil moisture status of the studied habitat, late-May is suggested as the optimum time for the entrance of livestock to the studied rangeland. This is because most Poaceae members of the region have entered the panicle emergence stage at this time, and the key, dominant, and herbaceous broad-leaved plants of the studied region have entered the flowering stage and the land is therefore in suitable condition in terms of soil moisture. The best time for collecting the studied species' seeds is mid-June to late-June/early-July and after this date, the species' seeds will begin to fall and cause problems for seed collection. Knowledge of habitat environmental characteristics and ecological needs of plant species has an effective role in suggesting species that are compatible with environmental conditions in similar areas. Therefore, the results of this study can be used to conserve this species and improve and reclamation of the areas with similar conditions, which is one of the important achievements of this study.

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