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Ecological Niche Modelling and Potential Distribution of *Artemisia sieberi* in the Iranian Steppe Vegetation

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Abstract: *Artemisia sieberi* Besser occurs in many parts of the Irano-Turanian floristic region, which is mostly distributed throughout the Iranian plateau, especially in Iran. This study aimed to identify the effect of the soil and topography variables on *A. sieberi* distribution. We used canopy cover data to fit models using generalized additive models (GAMs). The results showed that the response pattern of *A. sieberi* along with the gradient of soil clay, soil saturation moisture, soil nitrogen and soil acidity followed the monotonic increase model, and its canopy cover percentage augmented by increasing the values of the factors. Conversely, the *A. sieberi* canopy cover percentage decreased by increasing the amount of soil sand, bare soil and the geographic aspect. The *A. sieberi* responses are in contrast to the niche theory. The relationship between the species response pattern and the gradients of soil silt, soil salinity, lime percentage, organic carbon, altitude, land slope, litter, gravel percentage, stone percentage, mean annual precipitation and mean annual temperature followed a unimodal model (consistent with the niche theory). The optimal growth limits for these factors were 32%, 1.75 ds/m, 35%, 1.3%, 2000 m, 43%, 10%, 32%, 250 mm and 15 °C, respectively. Our results highlight that environmental factors, such as soil texture, amount of soil lime, mean annual precipitation, altitude and land slope, had quantifiable effects on the performance of *A. sieberi*. Our findings could provide useful information for improvement, restoration and conservation programs. However, a further comprehension of the species–environment relationship is needed to predict the effects of climate change on the species habitat.

Keywords: canopy cover; ecological factors; Generalized Additive Models; Irano-Turanian region; optimum growth; species distribution

1. Introduction

Artemisia sieberi Besser (Asteraceae) is a shrubby aromatic plant distributed in Palestine, Syria, Iraq, Afghanistan, Pakistan, Central Asia and Iran (in the Irano-Turanian floristic region) [1,2]. It occurs in many arid and semiarid rangelands of Iran (from the Alborz mountains southern slopes in the north to the Saharo-Sindian floristic region boundary in the south and from the Zagros Mountains eastern slopes in the west to the east of Iran). More than 25,423,578 hectares of vegetation types of the Iranian natural resources (about 33.9%)

are characterized by dominant and subdominant *A. sieberi*, which are mostly distributed throughout central Iran [3]. This species grows on different soil types, and it has a vast ecological distribution. *A. sieberi* is used for animal feeding, and because of its healing properties, it is also used as a medicinal plant [4,5]. Unfortunately, in recent years, disturbances such as grazing, land use changes and climate changes have caused the destruction of *A. sieberi* habitats. These threats have led to the destruction of vegetation, loss of biological diversity and erosion of the soil in many rangelands of Iran [6]. Destroyed rangelands are an important topic; in particular, conservation and rehabilitation of rangelands, monitoring of the vegetation dynamics and determination of suitable plant species that can be planted in areas with different environmental conditions should be considered [5]. Abiotic factors are one of the main components of the environmental niche [7,8]. Indeed, they have a major impact on the distribution and performance of plant species. In ecology, the geographical distribution of a species is predicted by quantifying the relationship between the species and the environment. On this basis, multiple hypotheses can be formulated in relation to the control of environmental factors that influence the distribution of the species [9]. It is crucial to understand the effects of the soil and topographic factors on the distribution of plants and vegetation restoration to improve the fragile ecosystems of damaged land. Knowledge of Artemisia response to environmental variables, and modeling of Artemisia occurrence, is essential for using this species in the reclamation of arid and semi-arid lands. For the species niche modeling, many analytical approaches can be used to answer the fundamental question 'what are the environmental factors controlling the species performance and distribution?' [10]. Canonical correspondence analysis and generalized additive models are among the methods most used for analyzing the reaction of plant species to environmental factors [11,12]. Generalized additive models [13,14], a powerful extension of GLM, are increasingly used for species modelling [15–19] because they do not assume any general shape of the response prior to the estimation [20].

In Iran, several studies have been conducted to investigate the factors that affect the distribution of *A. sieberi* as a result of environmental changes [5,21–27]. Jalili and colleagues studied the *A. sieberi* habitats in Iran and recognized important ecological differences in the functional characteristics of diploids and polyploids [28]. Mousaei Sanjerehei and Rundel determined that the most significant factors influencing the distribution of *A. sieberi* in Iran were annual precipitation and annual mean temperature [29]. In this research, we studied the role of the soil and topography in the function of *A. sieberi* in the Irano-Turanian floristic region of Iran. The following question was discussed: What are the responses and ecological requirements of *Artemisia sieberi* regarding some of the environmental variables?

2. Materials and Methods

Sixteen research sites, which presented different vegetation types of *A. sieberi* [30], were selected in Iran to have the maximum range of changes in altitude and geographical dispersion (29°23′–37°16′ N, 49°35′–60°05′ E). The range of altitude was between 560 m a.s.l. in Zirkooh Ghayenat (south Khorasan province) and 3000 m a.s.l in the mountainous areas of Hossein Abad Rain (Kerman province) (Figure 1).

A systematic-random method was used for the vegetation sampling [31,32]. Thirty sampling plots were positioned along five transects (6 sampling plots, with a random starting point, were placed in each transect) so that samples were collected in the range of the *A. sieberi* distribution in each site (480 sampling plots in total) during 2018 to 2020. The geographical coordinates of the plot locations were recorded using the Global Positioning System (GPS). The number of individuals per plot was evaluated and a visual estimation of each plot was performed to determine the vascular plant density and the canopy cover percentage. Additionally, stone and gravel percentage, bare soil percentage and litter percentage were estimated in each plot. The minimal area of the sampling plots was calculated for each sampling site and was selected to be 25 m^2 [33]. Vascular plants were identified using the Flora Iranica [34] and Flora of Iran [35].

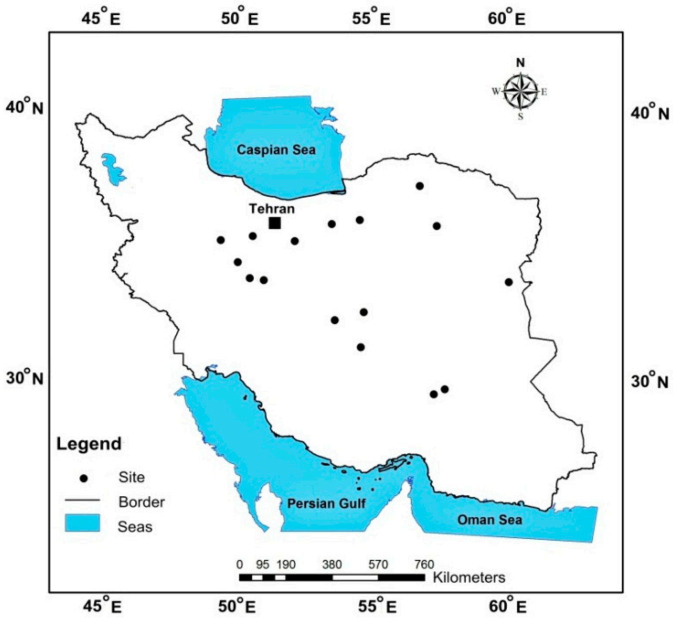

Figure 1. Location of studied sites in Iran.

The topographic characteristics (altitude, land slope percentage and geographical direction) of each plot were investigated after the analysis of the sampling network in each site. Four directions (90, 180, 270, 360 degrees) were used to register the geographical direction [36]. Then, the equation of Beers et al. [37] was used to enter the geographical direction in the analysis (Equation (1)).

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

where A' is the converted value of direction and A is the azimuth of aspect in degrees, measured clockwise from north. The influence of the soil on the *A. sieberi* distribution was evaluated by sampling the soil to the root depth of the plant (0–30 cm above the soil surface) in each plot (a total of 480 samples). The soil sample of each plot was taken in three replications (composite sample).

The soil's physical and chemical properties were measured. In particular, soil texture was determined through the hydrometer method [38], EC was measured using the saturated extract and EC meter [39], pH was established using the saturated mud and pH meter [40], TNV% was calculated through the titration method, organic carbon% was measured through the Walkley-Black method [41], total nitrogen was evaluated using the Kjeldahl method, and soil saturation moisture (%) was determined by drying saturated mud inside the oven [42].

Prior to data analysis, spatial autocorrelation of plots was performed using the Mantel test [43] with PC-ORD 4.17 software [44].

The *A. sieberi* response to environmental factors changes was predicted using the generalized additive model (GAM) (Equation (2)) [36]. The canopy cover percentage measurement is easier when the species habitat is less degraded, because of the high correlation between the species yield and canopy cover percentage (Pearson correlation = 0.856, p = 0.000). This factor was measured as a response variable [45,46].

$$g(\mu) = \alpha + \sum_{j=1}^{p} f_j(X_j) \tag{2}$$

where f_j is unknown and smooth functions and X_j are predictive variables. Using the advanced scatter plot smoothing techniques, f_j is evaluated from the data. Log link function analysis and Poisson error distribution were used to fit the generalized additive model (they entered the model individually to avoid an over-fitting of the predictive variables).

Smooth terms were fitted using a cubic spline smoother with three degrees of freedom, and a quasi-Poisson distribution was used for the Poisson [8,47].

The variables that influenced the *A. sieberi* performance were classified through the Akaike information criterion (AIC) [48]. The models showing higher parsimony (lower Akaike information criterion, AIC), when compared to the null model, were selected [8]; the smaller the AIC value was, the more appropriate the proposed model for fitting the species response curve (Equations (3) and (4)) [49].

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (Qi - \hat{Q}i)^2}{n}} \quad (3)$$

$$\text{AIC}= \text{nln}\ (RMSE) + 2\text{p} \quad (4)$$

where $RMSE$ is the root-mean-square deviation, n is the number of observations, Qi is the observed value, $\hat{Q}i$ is the fitted value, and p is the number of model variables. Canoco software version 4.5 [50] was used for data analysis.

3. Results

Table 1 illustrates the average values of the environmental factors studied in the habitats.

Table 1. The average values of the environmental factors in the *A. sieberi* habitats.

Environmental Factors	Mean ± Stdev.	Environmental Factors	Mean ± Stdev.
Sand (%)	63.6 ± 12.8	Altitude (m)	1796.6 ± 525.7
Silt (%)	20.6 ± 8.7	Aspect (converted value of azimuth)	1.07 ± 0.75
Clay (%)	17.1 ± 7.5	Slope (%)	11.4 ± 9.3
EC (dsm-1)	2.4 ± 3.9	Bare soil (%)	45.4 ± 29.1
pH	7.9 ± 0.3	Stone and gravel (%)	33.1 ± 22.2
Lime (%)	21.8 ± 8.6	Litter (%)	5.4 ± 5.3
Organic carbon (%)	0.32 ± 0.3	Mean annual temperature (°C)	15.3 ± 1.7
Total nitrogen (%)	0.03 ± 0.3	Mean annual precipitation (mm)	185.7 ± 90.3
Soil saturation moisture (%)	27.7 ± 6.7	Latitude (Decimal degrees)	33.69 ± 2.68

Table 2 illustrates that most of the studied variables had a significant effect on the *A. sieberi* canopy cover percentage ($p < 0.01$), as shown by the generalized additive model with Poisson error distribution.

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

Environmental Variable	F *	P *	AIC Value	Environmental Variable	F *	P *	AIC Value
Sand (%)	18.9	0.0000 **	1840.3	Altitude (m)	44.5	0.0000 **	1590.4
Silt (%)	87.2	0.0000 **	1262.3	Aspect	4.2	0.0001 **	2066.8
Clay (%)	23.2	0.0000 **	1812.4	Slope (%)	24.1	0.0000 **	1754.8
pH	6.6	0.0003 **	2035.7	Bare soil (%)	19.2	0.0000 **	1847.2
EC (dsm-1)	11.5	0.0000 **	1966.2	Stone and gravel (%)	3.1	0.027 *	2095
Lime percentage (%)	80.8	0.0000 **	1296.4	Litter (%)	6.4	0.0003 **	2034.8
Organic carbon (%)	24.3	0.0000 **	1771.4	Mean annual temperature (°C)	52.4	0.0000 **	2178.9
Total nitrogen (%)	24.5	0.0000 **	1761.6	Mean annual precipitation (mm)	125.7	0.0000 **	1572.6
Soil saturation moisture (%)	16.1	0.0000 **	1769.3	Latitude (Decimal degrees)	17	0.0000 **	2594.3

* Significance at the 5% level. ** Significance at the 1% level.

The A. sieberi response curve to each of the effective environmental variables was evaluated (Figure 2).

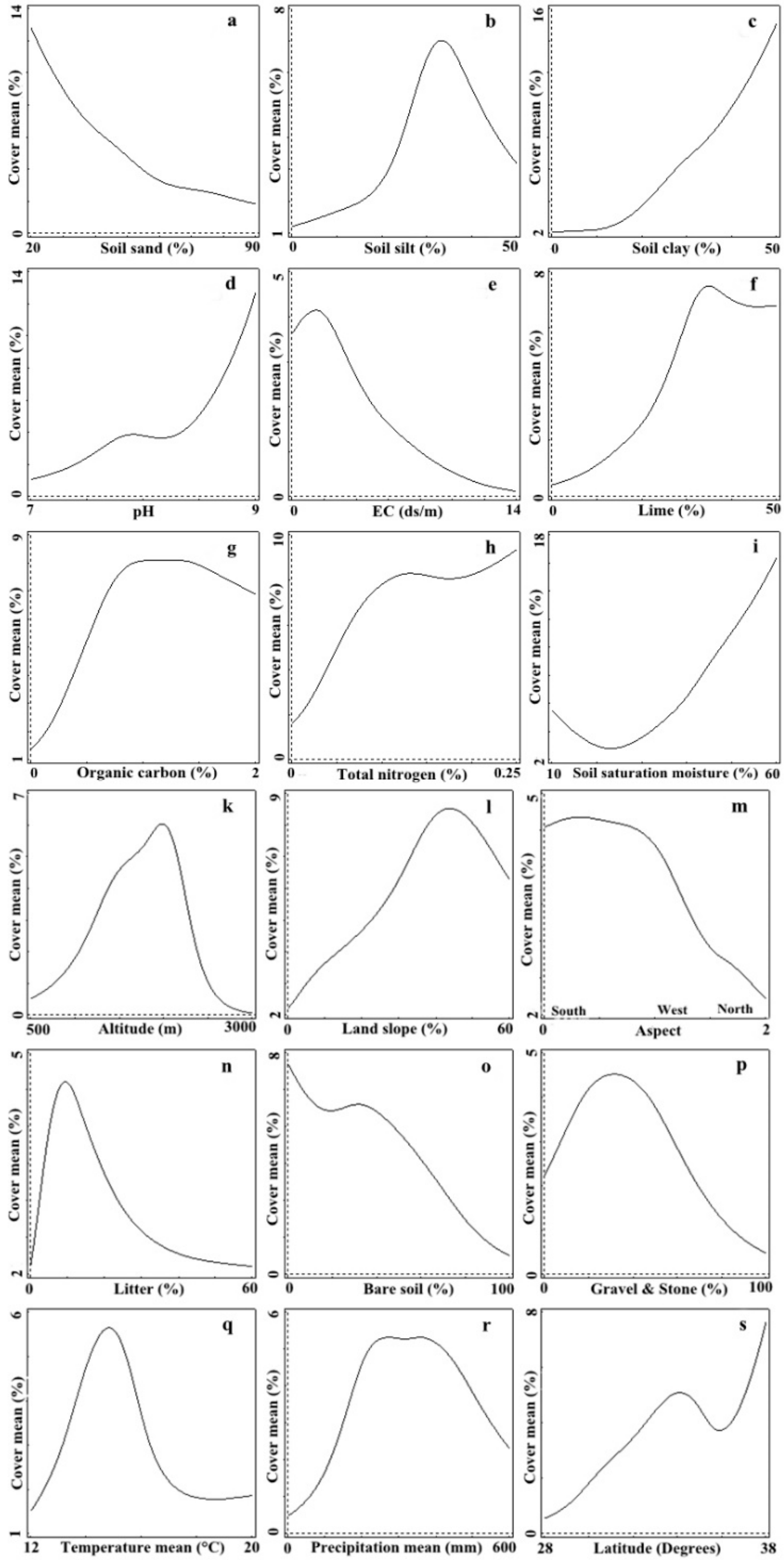

Figure 2. *A. sieberi* responses along the gradient of environmental factors.

The *A. sieberi* unimodal response to the soil silt (Figure 2b), altitude (Figure 2k), land slope (Figure 2l), gravel and stone (Figure 2p), litter (Figure 2n), temperature (Figure 2q) and precipitation gradient (Figure 2r) spanned its central borders, respectively from 1.6 to 43% (optimum 32%), 560 to 2788 m (optimum 2000 m), 0 to 60% (optimum 43% (on south-facing slopes)), 0 to 97% (optimum 32%), 0 to 54% (optimum 10%), 12 to 19.7 °C (optimum 15 °C) and 78.9 to 600 mm (optimum 250 mm). Increases in the amount of these factors, more than the optimum, resulted in a reduction of the *A. sieberi* canopy cover percentage. The species' performance augmented up to a soil salinity concentration of 1.75 ds/m; the canopy cover percentage decreased with further increases in the soil salinity (ranging between 0.09 and 12.8 ds/m). Therefore, *A. sieberi* is distributed in soils with relatively low salinity. The *A. sieberi*'s response to the soil lime percentage almost followed the asymmetric unimodal (Figure 2f): the plant performance initially increased slowly and then rapidly, approaching an exponential growth rate. However, when the amount of soil lime increases (more than 35%, ranging between 1.7 and 48.7%), the *A. sieberi* canopy cover percentage decreases until it stabilizes at a certain value.

Considering the soil organic carbon gradient, *A. sieberi* had its maximum response at 1%; increases in the organic carbon percentage from 0.02 to about 1.3% increased the species canopy cover percentage; an organic carbon percentage higher than 1.3% reduced the species distribution and presence (Figure 2g). According to the data of the *A. sieberi* response to the pH, this species is distributed in alkaline soils (following the positive exponential model).

The soil sand percentage showed a negative exponential trend (Figure 2a): as the soil sand value becomes larger, the *A. sieberi* performance approaches zero. Conversely, the soil clay and soil saturation moisture gradients showed a positive exponential trend (Figure 2c,i): increases in these factors increased the canopy cover percentage of the studied species. Considering the bare soil gradient, the *A. sieberi* response curve showed an almost negative linear trend: *A. sieberi* had the lowest performance with the highest percentage of bare soil (Figure 2o).

The *A. sieberi*'s response to the total nitrogen percentage almost followed the monotonic increase model, and the canopy cover percentage increased with increasing values of nitrogen (Figure 2h). In mountainous areas, changes in the geographical direction of the slope also affected the performance of the studied species; in particular, the *A. sieberi* performance reached its highest value in the southern facing slopes (Figure 2m), while the lowest performance was observed in the north facing slopes.

The species' response to changes in latitude was bimodal. Increases in latitude up to 35° resulted in an increased canopy cover percentage, while increases in latitude from 35° to 36° led to a reduction of the canopy cover percentage; however, further increases in latitude increased the canopy cover percentage. The lower limit of the species' presence was observed at latitude 28° (Figure 2s).

4. Discussion

The determination of the species response to the studied environmental factors represents one of the basic issues in ecology. Response curves allow the estimation of the species optimum and the niche width (tolerance) [51–55]. Statistical models play an important role in this regard [56]. *Aremisia sieberi* belongs to the steppe vegetation of Iran and is important in terms of forage production and medicinal properties [5,26,57]. However, the *A. sieberi* habitats are at risk due to the extra exploitation of these ecosystems during the past decades [58]. In this research, the GAM model was used to investigate the *A. sieberi* response to gradients of different environmental factors. The studied species' ecological needs were also studied.

In the studied habitats, *A. sieberi* has a significant yield; this aspect is highlighted by the average dry forage production, which is 66 kg per hectare. The forage production differences are due to both the habitat potential and the presence of disturbances, such as livestock grazing; this issue has also been mentioned by Khosravi Mashizi and Sharafatmandrad [58].

As reported also by other researchers [5,26,59], the data of this study showed that the *A. sieberi* performance was significantly affected by 18 variables, which were soil texture, lime, mean annual precipitation, altitude and land slope.

The *A. sieberi* response to the main environmental factors that affected the plant performance was exponential or unimodal; specifically, the response curves were mostly asymmetric unimodal.

According to the soil texture response curves, *A. sieberi* was found in areas that were characterized by a high soil clay percentage. This soil textural class causes the production of meso- and micro-porosities; indeed, these areas present the greatest amount of plant available water. As reported by other researchers [60,61], *A. sieberi* needs relatively more water compared to other species. Additionally, the lowest performance of *A. sieberi* was recorded in areas with the highest soil sand percentage and lower water retention [5].

Soil texture has an important function in the plants distribution and is involved in the soil humidity percentage, water holding capacity, plant elements availability and plant ventilation and rooting [62–64].

A. sieberi showed a positive exponential response to the soil acidity gradient, therefore, it has a strongly alkaline ecological niche. Piri Sahragard and Zare Chahouki [26] reported that *A. sieberi* is more compatible with soils characterized by a higher pH; moreover, soil acidity has a major role in the control of nutrients solubility [65]. Consequently, the pH level could be considered an important factor for the species distribution in the area. Our results illustrated that *A. sieberi* followed an asymmetric unimodal model in response to soil salinity. A low salinity rate (1.75 ds/m) caused significant abundance of *A. sieberi.* However, a higher soil salinity level caused an increased soil osmotic pressure (osmotic stress). This led to a reduction in the plant yield due to a lower water absorption and reduced plant metabolism; ultimately, the enzyme activity was also inhibited (ion toxicity). The studied areas presented a strongly different soil lime content (1.7–48.7%), and the *A. sieberi* response to the level of lime followed an asymmetric hump-shaped curve (the optimum was at 35%). The data of our study showed that *A. sieberi* tolerates various lime concentrations, although has a higher distribution in soils with a relatively high lime percentage, as reported also by Hosseini et al. [5]. Hence, *A. sieberi* is positively correlated with the soil lime percentage. It can be deduced that *A. sieberi* is a calcicole plant, because lime increases soil alkalinity. The soil lime content also decreases the growth of plants that need acidic soil [66]. The soil lime content is also a source of calcium and magnesium and is related to higher water retention [67,68]. All these aspects influence the distribution of *A. sieberi* in the studied region. *A. sieberi*'s response to the soil nitrogen percentage almost followed the monotonic increase model: the plant performance initially increased rapidly and then augmented slowly. A high soil nitrogen percentage (the optimum was at 0.25%) is related to increased soil microorganism activity, litter decomposition and plant growth and is considered a fertility indicator [69]. An increased soil organic carbon content (the optimum was at 1.3%) causes the formation of larger aggregates in the soil; the higher soil structure stability and increased number of large pores derived lead to an increased permeability coefficient and reduced erosion, as illustrated also by Lado et al. [70].

Considering *A. sieberi*'s response to the land slope percentage, the data of our study showed that plant performance was higher in the southern moderate slopes in mountainous areas. Davis et al. [71] illustrated that slopes have an average correlation with the species composition. The reason for the decreased presence of *A. sieberi* on slopes higher than 43% seems to be the reduction of the establishment of *A. sieberi* seeds due to an increased percentage of bare soil, stone and water erosion; this was also confirmed by other researchers such as Alavi et al. [72]. The soil's porosity in the moderate slopes is increased and more seeds are exposed to moisture; consequently, a higher number of seeds germinate, leading to increased reproduction [73]. According to the data about the performance of *A. sieberi* in response to altitude changes, this species was more present in the middle altitudes (about 2000 m). Hosseini et al. [5] illustrated that the optimum altitude was about 2300 m in the Poshtkouh area (local study), in central Iran. The increased presence of *A. sieberi* in the middle altitudes could be due to a combination of factors, such as adequate ecological factors and high levels of species turnover. As discussed also by other authors [74–76], this highlights the importance of the balance between communities and environment.

The highest canopy cover percentage was observed in the south aspects (south, southwest and southeast). Moreover, the studied plant distribution was also affected by the geographical direction due to the amount of plant available water and light [77]. As stated by other authors [19,78–81], the *A. sieberi* distribution was influenced by terrain and climate-related factors. It seems that *A. sieberi* is a xerophyte and helliophyta species.

In addition, the *A. sieberi* maximum response was recorded with the highest soil saturation moisture percentage (≥60%). The texture and structure of the soil influence this factor and affect the pore size distribution of the soil, soil water storage and plant available water [82,83]. The response of the studied species to the soil saturation moisture percentage is similar to the response given to the soil clay percentage.

A decreased permeability (decreased soil moisture storage) and soil erosion could affect the low *A. sieberi* presence and canopy cover percentage recorded in the areas with the highest percentage of bare soil. As reported by other researchers such as Carcey Hincz and Diaz Aguilar [29], Wassie et al. [84] and Laris and Wardell [85], this influences the germination deficiency and vegetation establishment.

The *A. sieberi* growth decreased with a high stone and gravel percentage (>30%), which characterizes the Zagros Mountains [67].

With an increasing amount of litter up to 10%, the abundance of *A. sieberi* increased; a further increase in the litter amount led to a decreased presence of this species. It seems that the early life stages of this species may benefit from a low amount of litter; indeed, with medium and high litter amounts the frequency of *A. sieberi* decreased, which may be due to reduced germination. This was in accordance with the results of a previous study on other plant species [86].

The relationship between *A. sieberi* performance and mean annual temperature followed a hump shape: the minimum temperature was 12 °C and the maximum was 19.7 °C (the optimum was at 15 °C), which may suggest an adaptation to a narrow climate niche (stenothermal); this was also reported by other researchers [87,88].

The probability of *A. sieberi* presence in the Iranian steppe vegetation, with an annual precipitation of about 200–400 mm, was the highest. Canopy cover and presence of the species dramatically decreased with an annual precipitation higher than 400 mm or lower than 200 mm. Sanjerehei and Rundel (2017) [87] and Amiri et al. [27] also reported a decrease in the *A. sieberi* yield with increasing precipitation.

The increase of latitude up to 34° resulted in an increased canopy cover percentage, while increases in latitude from 34° to 36° led to a canopy cover reduction; however, further increases in latitude increased the *A. sieberi* canopy cover percentage. The lower limit of the species' presence was observed at 28° of latitude. In general, *A. sieberi* tended to grow at the middle latitude (34–35°) and middle-lower altitude (1700–2200 m) with middle lower precipitation (200–400 mm) and middle temperatures (14–16°). However, this species also had a higher yield at a higher latitude (38°) with lower altitudes in the Iranian steppe vegetation. These data are in accordance with the results of a previous study [3]. The species' response to changes in latitude was bimodal. This model shows that a superior competitor has displaced this species from its optimum in a certain range of environmental conditions [89]. However, the nature of the environmental process, which may link indirect variables to direct variables, can affect the ecological relationship [12]. Therefore, it seems that the use of indirect predictors with a known relationship to direct variables that affect plant performance is often not suitable for statistical modeling. In conclusion, environmental variations (precipitation, temperature, sunlight, etc.) resulting from latitudinal gradients had a great influence on the spatial distribution of *A. sieberi* in the studied areas.

5. Conclusions

The potential plant species response to environmental variables changes can be predicted based on the species distribution, using niche models. Consequently, adequate species habitats can be defined; this has been increasingly used by natural resource managers to plan biodiversity conservation management, to assess climate impact and for land use activities. Because of the importance of the presence of *A. sieberi* in the steppe vegetation of Iran [26,88], up to date knowledge of its distribution is necessary for the ecosystem management planning. According to our results, the distribution of *A. sieberi* is described by the GAM and a reduction in abundance and performance of the studied species is explained by the constraints of environmental factors. The response of *A. sieberi* to environmental factors can be used to explain abiotic limitations, range management, conservation, improvement and restoration of degraded habitats of *A. sieberi*. We concluded that environmental factors, specifically soil texture, soil lime amount, mean annual precipitation, altitude and land slope, had quantifiable effects on the performance of *A. sieberi*. An improved understanding of these species-environment relationships in the context of natural climatic fluctuations will also aid in better prediction of the effects of climate change on the species habitats. In addition, due to the contribution of biotic interactions, interaction between variables and extreme environmental stress to the species response shape, it seems that further studies are needed to develop modeling approaches that consider these factors in relation to the species distribution. These findings will be used to complete the quantification of its ecology and the risk of anthropogenic activities.

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