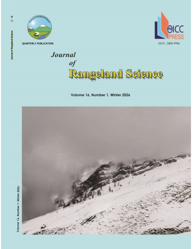

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Modeling *Stipa Arabica* Trin and Rupr. Habitat Displacement in Central Iran Using Ecological and Climate-based Approaches

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Original Research

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Abstract:

One of the main concerns of rangeland managers is to understand the factors that cause climate change and the effects of these factors on the main factors of rangeland management such as vegetation. Climate change in the rangelands of the highlands causes a decrease in biodiversity and deterioration in the downstream areas. This study aimed to predict the future habitat displacement of Stipa arabica Trin and Rupr. in the rangelands of Isfahan, Yazd, Semnan, and Kerman provinces, Iran under climate change conditions. The research objectives include identifying key environmental factors influencing Stipa arabica distribution, modeling its habitat suitability, and assessing potential shifts in elevation due to climate change. A predictive habitat map was developed by employing a logistic regression based on environmental variables, species presence/absence data, and geographic information system (GIS) analysis. To achieve this, key species associated with Stipa arabica were identified through expert interviews, and then, habitat characteristics were analyzed based on species behavior. Data on vegetation cover and environmental factors were collected from the station established by 2020, and habitat suitability was modeled in ArcGIS 10.3. The Kappa coefficient was used to assess model accuracy. The Kappa coefficient was 86, which according to the classification by Koch and Smith, falls into the category of models with good accuracy. The results indicate that Stipa arabica currently occupies elevations between 1,600 and 2,550 m above sea level, with a 75–100% probability of occurrence across approximately 5.2 million ha (10.7% of the study area). However, climate projections suggest that by 2050, its suitable habitat will shift to higher elevations 1,750–2,800 m under scenario (RCP 4.5) and 1,850–3,050 m under scenario (RCP 8.5). As temperatures rise due to climate change, the total suitable habitat area for Stipa arabica is expected to decline, forcing its migration to cooler, higher-altitude regions. To mitigate the impact of climate change on Stipa arabica, it is recommended that conservation efforts focus on the protection of higher-altitude habitats and the establishment of ecological corridors to facilitate species migration. Additionally, future research should explore adaptive management strategies for maintaining rangeland biodiversity in response to ongoing climate change.

Keywords: Climate change; Logistic regression; Climate scenario; Species distribution model

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1. Introduction

Grasslands and rangelands play a crucial role in maintaining biodiversity, providing ecosystem services, and supporting livestock and pastoral communities. However, climate change and land-use alterations are increasingly threatening these ecosystems, leading to habitat shifts and biodiversity loss. One of the species vulnerable to such environmental changes is Stipa arabica, a perennial grass species widely distributed in arid and semi-arid regions. Despite its ecological importance in stabilizing soil, preventing desertification, and serving as a forage source, limited research has been conducted on the potential impact of climate change on its habitat distribution. Recent studies have highlighted the role of environmental variables such as temperature, precipitation, and soil characteristics in determining the spatial distribution of plant species. Climate change projections suggest that rising temperatures and shifting precipitation patterns will significantly alter the geographic range of many plant species, forcing them to migrate to higher elevations or more favorable climatic zones. Various modeling approaches such as species distribution models (SDMs) and statistical regression techniques have been employed to predict such habitat shifts. Logistic regression, in particular has been widely used to assess species-environment relationships and develop predictive maps for habitat suitability. However, the application of this approach to Stipa arabica in Iran's central rangelands remains largely unexplored (Elith & Leathwick, 2009).

Global climate change is one of humanity's most serious challenges (Seddon et al., 2016). Since 1880, the average global temperature has increased by 0.065 degrees Celsius every decade due to significant changes in precipitation patterns (Ma et al., 2017). Various reports have introduced climate change as a transformation factor in physiology, phenology, species distribution range, and ecological stability in different ecosystems (Ferrarini et al., 2019; Gillison, 2019; Sintayehu, 2018). Climate change causes the extinction of some plant species or the distribution of others (IPCC, 2018). In response to climate change, plant species move to areas with better environmental conditions (Moritz & Agudo, 2013). Evaluating and analyzing spatial information about plant species in the environmental sciences is an effective step in planning and managing an ecosystem. A critical component of this field is identifying how plant species are distributed and the complex nonlinear interactions between variables (Cutler et al., 2007). Understanding and identifying the relationship between vegetation cover and environmental factors affecting plant species distribution is one solution to managing rangelands and exploiting valuable range species (Piri Sahragard et al., 2015). Species distribution models are suitable tools to predict plant and animal distribution (Guisan & Zimmermann, 2000; Miller, 2010). Species distribution models simulate suitable species based on species presence points and environmental characteristics (Yi et al., 2016). They effectively predict future plant species distribution and climate change effects on the ecosystem (Ghahramani & Moore, 2015).

Therefore, many studies have been carried out at the national and international levels. These include: (Abolmaali et al., 2018; Amiri et al., 2019; Borna et al., 2016; Khodagholi, 2022; Motamedi & Khodagholi, 2022; Naghi pour Barj et al., 2019; Sangooni et al., 2017). and at the global level, we can refer to the studies of (De Clercq et al., 2015; Manel et al., 1999; Priti et al., 2016; Rana et al., 2018).

Scientific reports show that in the last 100 years, the average global temperature has increased by approximately 0.74 degrees Celsius, while surveys conducted by the Meteorological Organization show that the average annual temperature of the country's stations (Iran) has increased by about 3.3 degrees Celsius. It is predicted that with an increase of 1.5 to 2.5 degrees Celsius in the Earth's average temperature, 20 to 30 percent of plant and animal species would be in danger of extinction (Habibi Nokhandan et al., 2018).

Given the ecological importance of Stipa arabica and the potential threats posed by climate change, this study investigates how its distribution may shift in response to future climatic scenarios in central Iran. Specifically, it aims to: (1) identify key environmental factors influencing the species' distribution, (2) develop a predictive habitat model using logistic regression and GIS-based analysis, and (3) assess potential habitat displacement under different climate change scenarios. The results will support the conservation and management of rangeland ecosystems by offering insights into the species' future distribution and guiding adaptive protection strategies.

2. Materials and methods

2.1 Location of the study area

The study area covers the central part of Iran, including Isfahan, Kerman, Yazd, and Semnan, located at longitudes 49.64 to 59.57 E and latitudes 26.48 to 37.33 N (Figure 1). The area of this region is 463,939 Km^2.

The precipitation in the studied area is the highest in the westernmost area and is about 540 mm on the outskirts of the Zagros Mountains. Moving towards the center of the study area, i.e., at Bafaq station, the lowest precipitation amount is around 48 mm. The average annual rainfall in the study area is 144.31 mm.

Stipa arabica Trin. & Rupr, is a perennial species and grows primarily in the temperate biome. It is native to Afghanistan, India, Iran, Iraq, Kazakhstan, Kirgizstan, Lebanon-Syria, North Caucasus, Pakistan, Palestine, Sinai, South European Russi, Tadzhikistan, Tibet, Transcaucasus, Turkey, Turkmenistan, Uzbekistan, West Himalaya, and Xinjiang. The plant structure is as follows: Life form (Raunkiaer): hemicryptophyte; Spinescence: absent; Succulence: non-succulent; Summer Shedding: perennating; Flowering and reproduction: Petal or tepal color: green; Sexuality and Reproductive Morphology:

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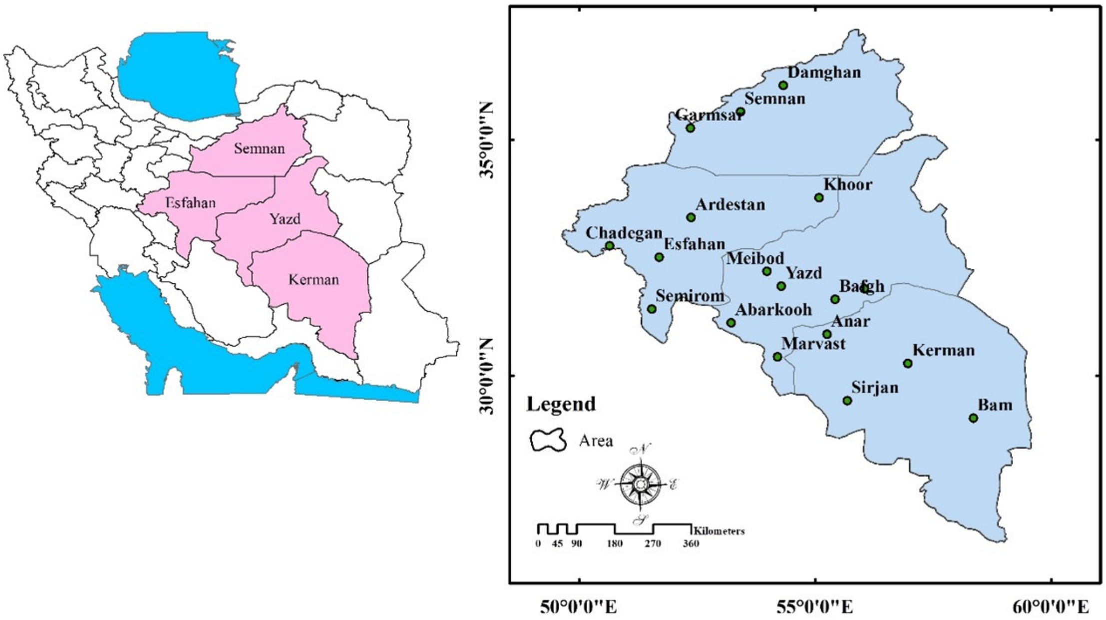

Figure 1. Location of the study area in Iran

Flowers hermaphrodite only; Sporangia or Seed Homogeneity: Homogeneous seeds-fruits; Leaf arrangement: alternate (one leaf per node), rosette; Leaf Type: entire; Leaf or leaflet margin: smooth; Stipule: absent (Figure 2) (Mozafarian et al., 2000).

The species Stipa arabica is one of the prominent members of the genus Stipa, widely distributed across the steppe and semi-steppe regions of Iran. Due to its unique ecological and morphological characteristics, this plant plays a significant role in arid ecosystems. It is drought-resistant and is used for soil conservation, livestock forage, and enhancing biodiversity. In some ecological studies, S. arabica has been identified as an indicator species of semi-arid ecosystems and plays an important role in the nutrient cycle of dry regions. It also exhibits seed autochory, utilizing the twisted awns to embed seeds into the soil (Mahdavi et al., 2013).

Figure 2. Stipa arabica

2.2 Research methodology

After interviewing local people and experts, recording the conversations, and analyzing them, a species with significant rangeland importance in soil conservation, fodder production, and resistance to environmental stress was selected. The initial distribution map of Stipa arabica was derived using the vegetation types map prepared as a part of the research project entitled "Identifying the ecological regions of the Country". The distribution presence points of the species were recorded by referring to the herbariums of Isfahan, Semnan, Yazd, and Kerman provinces, as well as the Research Institute of Forests and Rangelands and Flora books. Then, the minimum and maximum height of the species distribution and the current habitat map were determined by visiting different areas of the species' habitat. Also, using the land use map prepared by the Soil and Water Institute, land uses other than rangelands were removed from the polygons. The maps were modified with ArcGIS ver10.5, and the current species presence map was finalized. The pixel size was 4.9 × 4.9 Km and the number of pixel was 19324.

2.3 Environmental data

To draw the environmental data layer (raster layer) of 19 bio-climates Table 1, climatology data from 63 synoptic stations in the study area were used. Also, WorldClim.org, one of the data production websites, was used

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Table 1. Climatic variables used in modeling process

BIO	Mean
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (×100)
BIO4	Temperature Seasonality (standard deviation ×100)
BIO5	Maximum Temperature of Warmest Month
BIO6	Minimum Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

with an accuracy of 30 seconds to calculate future climate BIOs (year 2050). These data were obtained for two scenarios, RCP4.5 and RCP8.5, for the future period. Also, slope, aspect, and altitude maps were drawn as input of environmental data using the Digital Elevation Model (DEM) with 30 m accuracy in ArcGIS.

2.4 Predicting species geographical distribution

Logistic regression (Relation 1) was used to predict Stipa arabica habitat distribution. For this purpose, environmental variables were included in the logistic regression model as predictor variables (independent), and species presence and absence as response variables (dependent). The species vegetative behavior was calculated under current conditions, and the corresponding equation was determined. This equation was used to predict habitat in 2050 using the MRI-ESM2-0 general circulation model under 4.5 and 8.5 scenarios. This method was implemented in SPSS software Ver24, and its results were converted into maps using ArcGIS Ver10.5.

$$p = \frac{1}{1 + e^{-z}}$$
$$z = B_0 + B_1 x_1 + B_2 x_2 + \cdots + B_n x_n \qquad (1)$$

In the above equations,

z is a linear multivariate equation obtained from the Logit function, the dependent variable or response.

B_i represents the regression model coefficients, and

x_i represents the environmental independent variables.

To evaluate habitat prediction maps, the Kappa coefficient was used. According to studies, this index is the most appropriate method to measure the agreement between observed and predicted data (Liu et al., 2005). This index measures the degree of agreement between the prediction of plant species presence and absence and existing reality.

3. Results

The selection of key species for habitat prediction was based on the perspectives of both local people and experts. The criteria for selecting these species were determined through interviews with 15 local experts and 31 specialists from scientific centers and natural resource departments.

From the perspective of local people, the most important selection criteria included the species role as fodder for livestock, contribution to soil stabilization and conservation, involvement in mitigating climate change effects, and nutritional value for rangeland animals. Based on the frequency of these criteria, an initial selection of plant species was made. Both groups were then consulted again to assess the significance of the selected species, ultimately leading to the consensus that Stipa arabica was the most important species for habitat prediction.

Following species selection, a presence-absence matrix was created, incorporating environmental variables. Logistic regression was then used to model the relationship between species occurrence and environmental predictor variables, enabling the prediction of Stipa arabica's potential habitat distribution. For the studied species, the following regression equation was extracted, which represents the habitat prediction model for the se-

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lected species.

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P(St.ar)=[EXP((-1.411)+(0.0145*Bio1
+(0.001*Bio4)+(-0.152*Bio5)+(-0.205*Bio10)
+(0.158*Bio11)+(-0.002*Bio12)+(-0.015*Bio13)
+(0*Bio14)+(-0.014*Bio15)+(0.005*Bio16)
+(0*Bio17)+(0.008*Bio18)+(0.006*Bio19))]/1
+[EXP((-1.411)+(0.0145*Bio1((0.001*Bio4)
+(-0.152*Bio5+(-0.205*Bio10)+(0.158*Bio11)
+(-0.002*Bio12)+(-0.015*Bio13)+(0*Bio14)
+(-0.014*Bio15)+(0.005*Bio16)+(0*Bio17)
+(0.008*Bio18)+(0.006*Bio19))]
```

As is clear from the above relationship, out of 22 factors, 13 climate variables entered the equation.

3.1 Current map of the Stipa Arabica habitat

The current habitat map of the studied species was classified according to the value of each cell in four classes, including class 1 as 0-25% (unsuitable habitat), class 2 as 25-50% (habitat with low suitability), class 3 as 50-75 %, (habitat with good suitability) and class 4 as 75-100%, (habitat with very good suitability). The map of the current condition of the studied species is shown in Figure 2. The area of each class and its percentage of the total area of the region are presented in Table 3.

The current species presence map shows that this species is present in the western parts with a frequency percentage of 75-100% (very good suitability), and the percentage of the species presence decreases in the southern parts (Figure 3). The produced map was classified into four classes to determine the area each class occupies. The results showed that the probability of occurrence of this species is 75-100% in approximately 10% of the studied area, equivalent to 5.2 million ha (Table 2).

3.2 Prediction map of Stipa arabica's suitable habitat

After preparing the map of environmental factors, a map of the selected species suitable habitat was prepared in GIS using the models obtained from logistic regression. The maps obtained from the prediction of the logistic regression model show that under the 4.5 scenario, the species presence is observed as a spot in the western corner and the center of the studied area. Table 3 shows 75-100 class presence in 3.84% of the studied area (Figure 4). The habitat prediction results for scenario 8.5 show a substantial decrease in Stipa arabica's suitable habitat.The presence of the species with a percentage of 75-100% is only in the western areas, as a very small patch of the study area. This patch includes about 0.26% of the area. This species, with a presence frequency of 50 to 75% (relatively suitable), is found at an altitude of 2,000-2,500 m, occupying a surface equivalent to 25.92 percent (Figure 5 and Table 4).

4. Discussion

Based on our findings, logistic regression proves to be an effective method for mapping and predicting the optimal habitat for plant species. (Azarnivand et al., 2007). emphasize that the emergence and establishment of any plant species are influenced by environmental factors and interspecies relationships, with certain factors playing a dominant role. Identifying these key environmental determinants allows for the development of predictive models for species distribution.

Since plant distribution is shaped by multiple environmental variables, statistical methods such as regression and ranking are commonly used to examine species-environment relationships. The choice of method depends on research objectives and data characteristics. Ordination methods, while useful, do not allow for simultaneous analysis of all species in relation to environmental factors. In contrast, regression models enable the evaluation of species-specific responses, making them widely accepted for predicting species presence and absence as well as generating habitat suitability maps (Carter et al., 2006; Lassueur et al., 2006; Miller, 2005; Padalia et al., 2010; Safaei et al., 2013; Zare Chahouki & Zare Chahouki, 2010).

Logistic regression models the species presence or absence based on the known environmental variables. Consequently, if the key environmental factors are identified, species occurrence in the unobserved areas can be predicted. Our results indicate that under climate change conditions, Stipa arabica will lose a significant portion of its suitable habitat due to increasing temperatures. (Kane et al., 2017). report that Gramineae species are particularly sensitive to climate change, experiencing substantial reductions in their suitable habitat range as temperatures rise.

Although shifts in species distribution may aid survival, they also expose species to novel biotic and abiotic pressures, disrupting ecological interactions and threatening the stability of native plant communities (Dagnino et al., 2020). In this study, Stipa arabica was found at elevations between 1,600 and 2,550 m above sea level. Previous research by (Farahani et al., 2008). reports its distribution across a broader range of 890 to 3,300 m with the most occurrences between 1,100 and 2,800 m.

Model projections for 2050 suggest that climate change will alter the species' altitudinal range. Under scenario 4.5, suitable elevations will shift to 1,750–2,800 m whereas in scenario 8.5, they will increase to 1,850–3,050 m. As temperatures rise, Stipa arabica is expected to migrate to higher elevations with cooler conditions. This pattern aligns with global trends, where species shift to higher latitudes or altitudes in response to warming. Our projections indicate that Stipa arabica will lose over 60% of its current range under scenario

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Table 2. Current habitat suitability classes for Stipa arabica in the study area

Percentage	Habitat suitability	Area (ha)	Class
12.69	Unsuitable habitat	6,533,014	1
49.76	Habitat with low suitability	25,605,760	2
27.35	Habitat with good suitability	14,075,679	3
10.17	Habitat with very good suitability	5,237,434	4

Table 3. Suitability classes of Stipa arabica suitable habitat in the study area using scenario 4.5

Class	Area (ha)	Habitat suitability	Percentage
1	10,321,039	unsuitable habitat	20.05
2	36,091,234	habitat with low suitability	70.14
3	3,061,945	habitat with good suitability	5.95
4	1,977,670	habitat with very good suitability	3.84

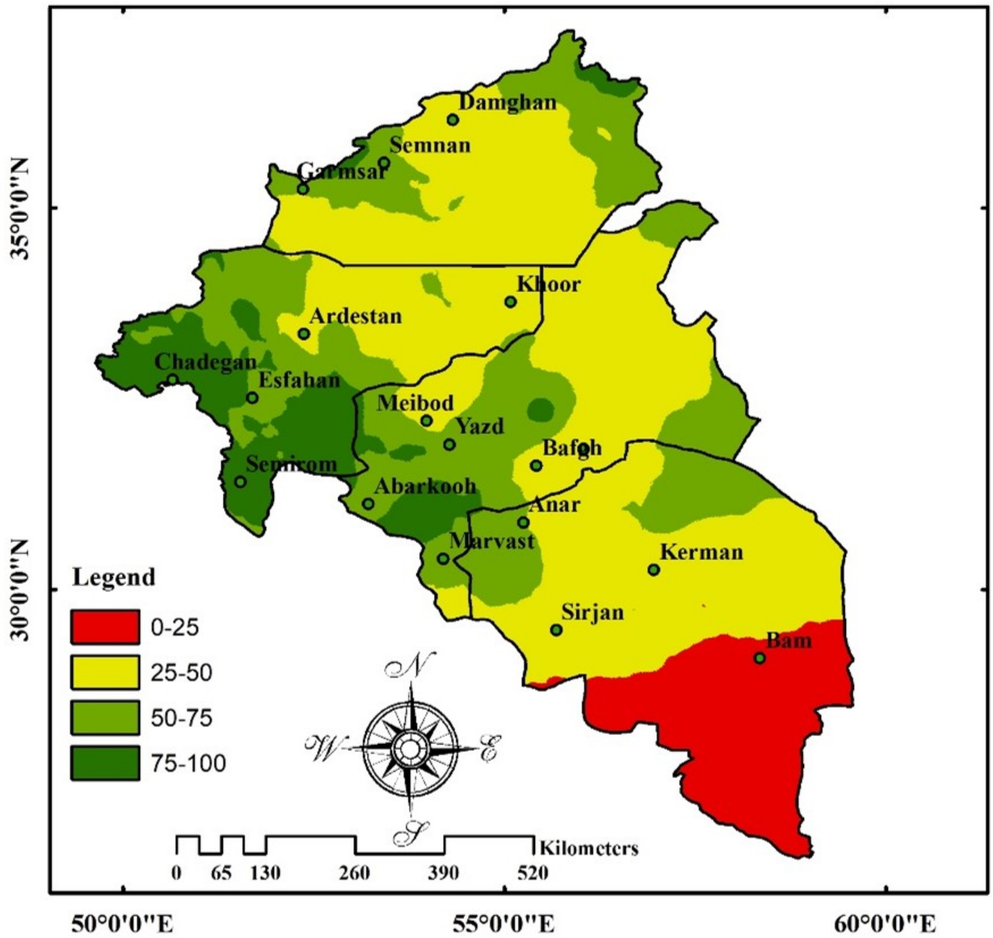

Figure 3. The map of Stipa arabica's current conditions

Table 4. Suitability classes of suitable habitat for Stipa arabica in the study area using scenario 8.5

Class	Area (ha)	Habitat suitability	Percentage
1	6,131,222	unsuitable habitat	11.91
2	37,847,871	habitat with low suitability	61.89
3	13,340,304	habitat with good suitability	25.92
4	132,490	habitat with very good suitability	0.26

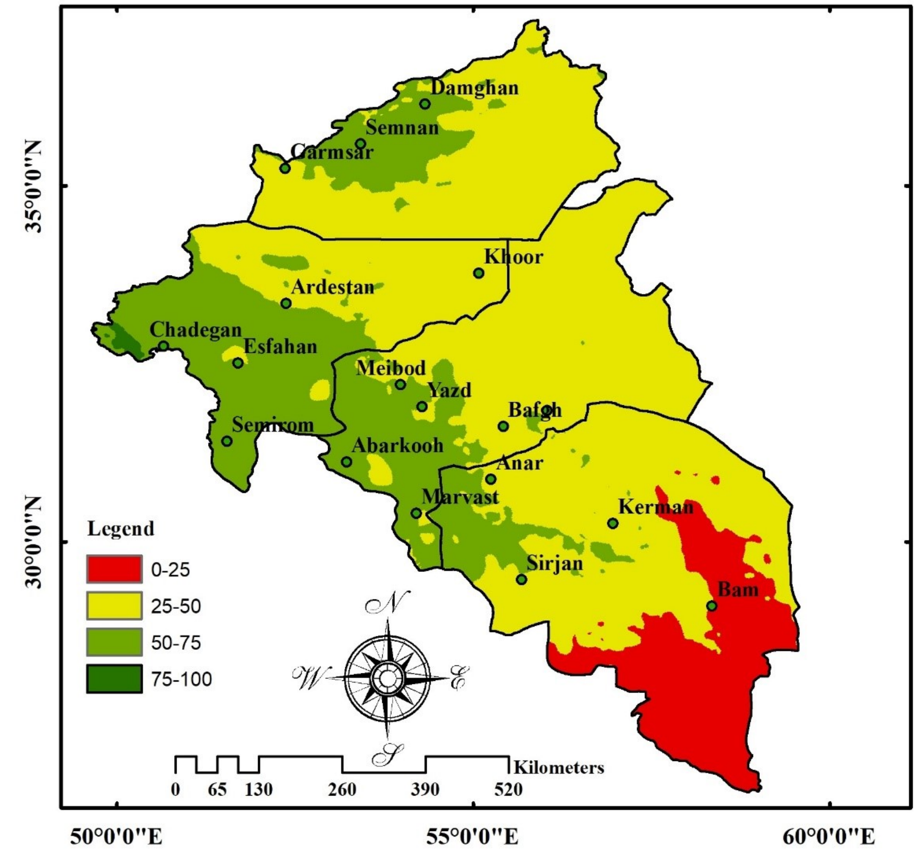

Figure 4. The prediction map of Stipa arabica's suitable habitat under scenario 4.5

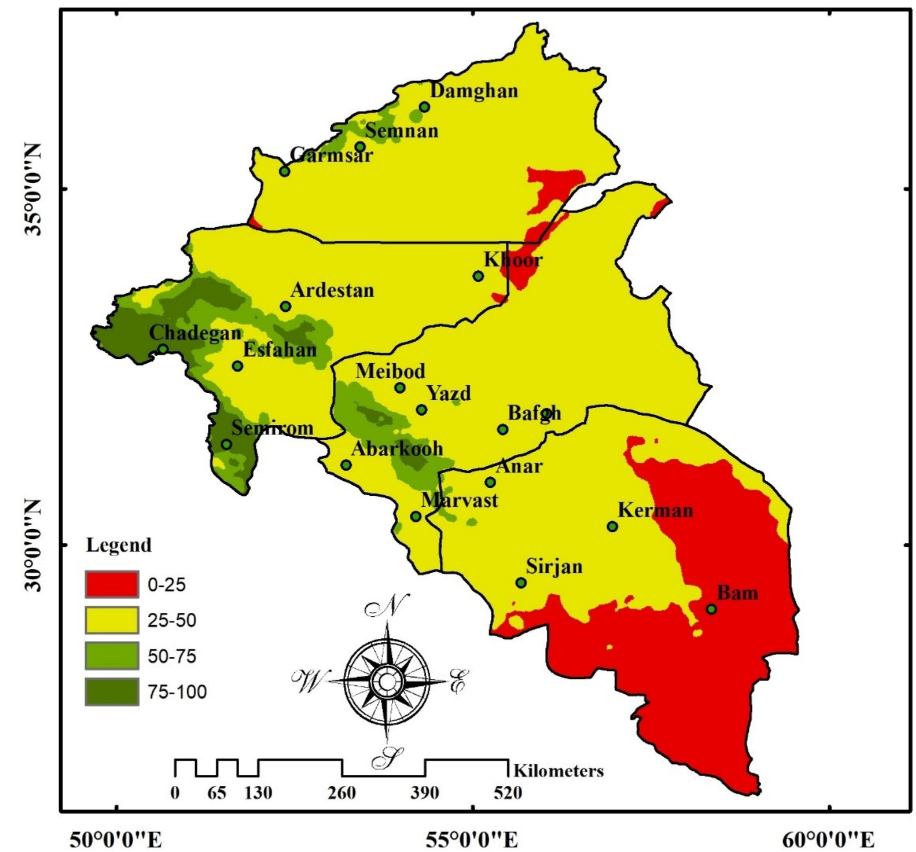

Figure 5. The prediction map of Stipa arabica's suitable habitat under scenario 8.5

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4.5 and more than 95% under scenario 8.5. Historical observations confirm that such upward migration is a key response of species to climate change.

However, additional factors such as soil composition, water availability, pollinators, competition, and human activity also influence species distribution (Thuiller, 2007). Given the complexity of these interactions, predicting their impact on a broad scale remains challenging. Numerous studies highlight the influence of climate on species distributions (Pearson & Dawson, 2003). reinforcing the need for predictive modeling.

In addition to its ecological role in forage production and soil and water conservation, Stipa arabica plays a critical role in mitigating wind erosion and controlling dust source centers in arid and semi-arid regions. Therefore, conserving this species can significantly contribute to reducing land degradation and improving ecosystem stability in Iran's central rangelands.

Given climate change's profound effects on rangeland ecosystems—including biodiversity, grazing capacity, species composition, and forage quality—understanding future habitat shifts is crucial. Assessing species vulnerability to climate change and developing adaptive management strategies is essential for conservation efforts. Since Stipa arabica not only serves as a valuable fodder species but also plays a critical role in soil and water conservation due to its extensive root system, preserving this species in Iran's central regions is vital. Effective natural resource management should integrate climate change adaptation strategies into conservation, restoration, and land-use planning.

The findings of this study highlight the significant impact of climate change on the distribution of Stipa arabica, emphasizing the need for adaptive management strategies. Given that this species plays a crucial role in soil and water conservation and serves as an important fodder source in rangelands, conservation efforts should focus on preserving its remaining suitable habitats.

To mitigate the adverse effects of climate change, natural resource managers should prioritize the following actions:

- Habitat Conservation and Restoration: Implement conservation measures to protect existing populations and restore the degraded habitats, particularly in higher altitudes where *Stipa arabica* is expected to migrate.

- Sustainable Grazing Management: to develop grazing plans that minimize overgrazing and promote the sustainable use of *Stipa arabica* to maintain rangeland productivity.

- Climate-Resilient Land Management: to integrate climate change adaptation strategies into land-use planning to support biodiversity and ecosystem stability.

- Monitoring and Research: to Establish long-term monitoring programs to track shifts in species distribution and assess the effectiveness of conservation measures.

- Community Engagement: to educate and involve local communities in sustainable rangeland management practices to ensure the long-term preservation of *Stipa arabica*.

- By incorporating these strategies, policymakers and natural resource managers can enhance the resilience of rangeland ecosystems and safeguard the ecological and economic benefits provided by *Stipa arabica*.

Authors contributions
All the authors have participated sufficiently in the intellectual content, conception and design of this work or the analysis and interpretation of the data (when applicable), as well as the writing of the manuscript.
Availability of data and materials
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests
The author states that there is no conflict of interest.

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