ISSN: 2476-6909; ECOPERSIA . 2020;8(1):41-46

Predicting the Present and Future Distribution of Medusahead and Barbed Goatgrass in Iran

ARTICLE INFO

Article Type
Original Research

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How to cite this article
Mousavi Kouhi S.M, Erfanian M. Predicting the Present and Future Distribution of Medusahead and Barbed Goatgrass in Iran. ECOPERSIA. 2020;8(1):41-46.

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Article History
Received: August 27, 2019
Accepted: October 18, 2019
ePublished: March 14, 2020

ABSTRACT

Aims Medusahead (*Taeniatherum caput-medusae* (L.) Nevski) and barbed goatgrass (*Aegilops triuncialis* L.) are two annual species that drastically affect rangelands worldwide. In the present study, the current distribution range of these species was investigated using ecological niche modelling (ENM), and then their distribution was predicted in 2040 and 2070.
Materials & Methods In this study, using 19 bioclimatic variables and the recorded presence locations, the current distribution of *T. caput-medusae* and *A. triuncialis* was predicted using MaxEnt. Moreover, changes in the distribution ranges of these species in the future (2040 and 2070) were estimated.
Findings According to the results, the mean temperature of the coldest quarter and Isothermality had the greatest effect on the distribution of *A. triuncialis* in the present and future. For *T. caput-medusae* distribution in the present, 2040, and 2070 the mean temperature of the coldest quarter had the highest effect on determining the potential distribution range of this plant. Accordingly, climate change will not affect the distribution range of barbed goatgrass, however, it may facilitate the expansion of medusahead to the upper elevations.
Conclusion In the present, comparing the two, barbed goatgrass had a higher probability to invade rangelands of Iran. Climate change might facilitate the invasion of medusahead to upper elevations. Grazing exclusion is advised to control the range expansion of these two species where they are present.

Keywords Ecological Niche Modelling; Taeniatherum caput-medusae; Aegilops triuncialis; Distribution Range; Climate Change

CITATION LINKS

[1] Adaptability and performance of industrial Eucalyptus species in Dashtestan, Bushehr ... [2] Seed source variation in growth performance and oil yield of Jatropha ... [3] Successful eucalyptus species for afforestation and development of green spaces under irrigation with sewage ... [4] Investigation on adaptability and performance of industrial Eucalyptus provenances at Khorramabad ... [5] The Danish/Fao international provenance trials of ... [6] Morphology and germination characteristics of Quercus brantii Lindl. acorns in ... [7] First year results of the teak provenance trial in Sri ... [8] Introduction of adaptable Eucalyptus species to the west of ... [9] A study of seed germination and seedling growth of eggplant ... [10] The allelopathic assay of Eucalyptus camaldulensis Labill on ... [11] Investigation on adaptability and performance of species and provenances ... [12] Effects of soil moisture stress on the growth of seedlings ... [13] Variations in seed and seedling responses to water stress in three ... [14] Growth and water relations of seedlings of two subspecies of ... [15] Evaluation of provenances of Eucalyptus camaldulensis and ... [16] Evaluation of Eucalyptus red gum species and provenances ... [17] Growth and wood properties of natural provenances, local seed ... [18] Variation in growth of Eucalyptus camaldulensis ... [19] Preliminary results of a provenance trial of Eucalyptus camaldulensis ... [20] Genetic variation in Eucalyptus camaldulensis ... [21] Physiological activity, in a semiarid environment ... [22] Provenance trial of Eucalyptus camaldulensis in Andhra ... [23] Provenances of Eucalyptus camaldulensis Dehnh ... [24] Variation in performance of Eucalyptus tereticornis provenances ... [25] Genetic variation in Eucalyptus camaldulensis ... [26] Variability of beech provenances in spring and autumn ... [27] Dendrometry and morphometry of Pinus ... [28] Adaptive genetic variation of Prosopis chilensis ... [29] Performance of Nuttall oak ... [30] Adaptability investigation of six species of gum tree for ... [31] Seed source effects on growth and flowering ... [32] Effects of seed source on first year growth of Quercus ... [33] Provenance variation in Podocarpus totara ... [34] Variation in seed and germination characteristics ...

Introduction

Invasive plant species occupy a wide range of geographical regions and compete with rare native species so that may lead to the extinction of those that cannot compete effectively [1, 2]. Ecological niche modelling (ENM) is one of the appropriate ways to determine the habitat suitability for plant species and preparing their distribution map [3]. Modelling the distribution of invasive species is one of the applications of ENM, and the resulted risk maps show the suitable areas that those invasive species can grow [4]. Altered distribution of the species during climate changes can be investigated by ENM [5].

Taeniatherum caput-medusae (L.) Nevski and *Aegilops triuncialis* L., commonly known as medusahead and barbed goatgrass, respectively, are two winter annual plant species from tribe Triticeae in Poaceae. *Aegilops triuncialis* is an allotetraploid and self-pollinating plant having several lateral stems with spikes, almost cylindrical-shaped. This species is native to Mediterranean regions and western Asia [6, 7]. *Taeniatherum caput-medusae* with a height between 20-60cm can be distinguished with its dried inflorescence in which spirally rotated spikelets in all directions give rise to a special shape. This species is native to southern and central Europe, northern Africa, and Asia [8]. Carbonized seeds of this plant have been found in early agricultural archaeological sites in Iran, where sheep and goats were first domesticated [9]. *Taeniatherum caput-medusae* and *A. triuncialis* are known as noxious invasive weeds worldwide [6, 10]. However, Iran might be their native distribution range. *Aegilops triuncialis* with the potential of dense growth in rangelands can affect annual species. Since the adult individual of this species is not palatable for large herbivores, its presence in rangeland may result in 50-75% reduced grazing capacity and a decrease in nutritional quality [11]. Having winter growth, *T. caput-medusae* can continue its root growth in the cold season producing a full-grown root system until the beginning of the spring, when the other species start to grow with early roots. Comparing to the other species, this species can absorb more water and nutrients that led to a high growth rate of this plant. This species can seriously damage the grasslands in which native species grow sparsely. This plant can also change the species composition in the communities being under grazing and fire disturbance [12, 13]. Moreover, these species lead to reduced ecosystem services and functional degradation [14, 15].

The aims of the present study are to (a) predict the current distribution range of these species using modeling approach, (b) estimate their distribution in the 2040 and 2070 using future climate layers. The results of this study can be used for predicting the behavior of these species in the other regions of the world. The present study is the first investigation on the distribution of these two plants in Iran.

Materials and Methods

Study area and Species presence data

The presence data of these species from Iran were used in the present study. The species presence data of *A. triuncialis* and *T. caput-medusae* was downloaded from the GBIF database [16] using dismo package [17] in R 3.4.0 software (R Core Team, 2017) [18]. Duplicate and very close points (those that their distance were below 10km) were removed from the downloaded data. The published floristic studies were also checked and some presence points were extracted from them.

Modelling

In the present study, Maximum Entropy (MaxEnt) modelling was used for predicting the potentially suitable habitats of *A. triuncialis* and *T. caput-medusae*. In this approach, a set of predictor variables and the species presence data are used for the modelling [19, 20]. When the absence data is not available, MaxEnt is one of the most efficient methods for the modelling of species distribution [21].

Nineteen bioclimatic variables (Table 1) related to precipitation and temperature with the 30 arc seconds resolution were downloaded from WorldClim (www.worldclim.org). Future climate layers in which climate change is included were downloaded from the Climate Change, Agriculture and Food Security (CCAFS) database under the A1B scenario (www.ccafs-climate.org). According to this scenario, the global content of carbon dioxide will increase until 2040 and decrease until 2070.

For eliminating the inter-correlated climatic layers from the analysis, first, the matrix of the values of the layer in the presence points was extracted using openModeller 1.0.7 [22] and then the Pearson's product-moment correlation coefficient among the layers was calculated in R. The layers with a correlation above 0.7 were removed. When removing the correlated layers, considering the ecological requirements of these two species, the most important layers were kept. The best regularization multiplier and product feature type combinations were analyzed using the ENMeval R package [23]. Maximum Entropy (MaxEnt) modelling approach was used because it is the most appropriate method for modelling species distribution using incomplete data [24]. MaxEnt 3.3.3k software was used for the modelling of these species [25]. The bootstrap method with 100 replications for each species was used for the model validation. For model evaluation, the area under curves (AUCs) of the receiver operating characteristic (ROC) curves were considered. Values of AUC range from 0.5 to 1. Models can be classified into five different categories: Excellent (AUC>0.9), good (0.8<AUC≤0.9), acceptable (0.7<AUC≤0.8), bad (0.6<AUC≤0.7), and invalid (0.5<AUC≤0.6). The effectiveness and involvement of each layer used in the modelling process can describe the importance of the layers on the presence of species. The final maps of the distribution of these two species were drawn using DIVA-GIS 7.5.0.0.

Table 1) The 19 climate layers applied for modelling in the present study

Climate variable	Abbreviation
Mean annual temperature	BIO1
Mean diurnal range	BIO2
Isothermality	BIO3
Temperature seasonality	BIO4
Maximum temperature of warmest month	BIO5
Minimum temperature of coldest month	BIO6
The annual temperature range (Bio5-Bio6)	BIO7
The mean temperature of wettest quarter	BIO8
The mean temperature of the driest quarter	BIO9
Mean temperature of warmest quarter	BIO10
Mean temperature of coldest quarter	BIO11
Annual precipitation	BIO12
Precipitation of wettest month	BIO13
Precipitation of driest month	BIO14
Precipitation seasonality (standard deviation/mean)	BIO15
Precipitation of wettest quarter	BIO16
Precipitation of driest quarter	BIO17
Precipitation of warmest quarter	BIO18
Precipitation of coldest quarter	BIO19

Findings

Based on Pearson's correlation analysis applied on all the bioclimatic layers, for each species (*T. caput-medusae* and *A. triuncialis*) six layers showing the correlation coefficient lower than 0.7 were used for the modelling. The AUC for *T. caput-medusae* and *A. triuncialis* in three periods, including the present, 2040 and 2070, along with the contribution of each layer in the final model are shown in Table 2.

Table 2) Six final layers in the modelling of distribution of *A. triuncialis* and *T. caput-medusae* in the present, 2040, and 2070; The numbers present in Table 1 indicate the contribution of each layer in the final model of the two species.

	Present	2040	2070
Aegilops triuncialis			
Variable			
BIO11	42.3	54.2	37.8
BIO3	35.9	25.4	44.6
BIO19	8.9	5.3	8.2
BIO4	5.2	6.5	3.2
BIO14	4.1	5.5	2.7
BIO8	3.6	3	3.5
Taeniatherum caput-medusae			
Variable			
BIO11	67.2	68.2	65.7
BIO8	15.7	10.8	13.9
BIO18	5.4	5.1	5.2
BIO3	5	11	3.7
BIO19	4	3.7	4.9
BIO7	2.8	1.3	6.6

For *A. triuncialis* distribution in the present time, mean temperature of the coldest quarter (Bio11), Isothermality (Bio3) and precipitation of the coldest quarter (Bio19) had the greatest influence on the species distribution with the contribution of 42.3, 35.9, and 8.9%, respectively. For 2040, mean temperature of the coldest quarter, Isothermality, and temperature seasonality (Bio4) had the highest impact on the distribution of this species, with the participation of 54.2, 25.4, and 6.5%, respectively. Finally, in 2070, Isothermality, the mean temperature of the coldest quarter, and precipitation of the coldest quarter had the greatest influence on the distribution of this species with the participation of 44.6, 37.8, and 8.2%, respectively. The results of the modelling for this species is presented in Figure 1.

For medusahead distribution in the present, mean temperature of the coldest quarter (Bio11), mean temperature of the wettest quarter (Bio8), and precipitation of the warmest quarter (Bio18) had the greatest effects on the distribution of this species, with the contribution values of 67.2, 15.7, and 5.4%, respectively. In 2040, mean temperature of the coldest quarter, Isothermality, and mean temperature of the wettest quarter had the highest effects on the distribution of this species, with the participation of 68.2, 11, and 10.8%, respectively. In 2070, mean temperature of the coldest quarter, mean temperature of the wettest quarter, and annual temperature range had the highest contribution to the distribution of this species with the participation of 65.7, 13.9, and 6.6%, respectively. Figure 2 shows the results of modelling for this species.

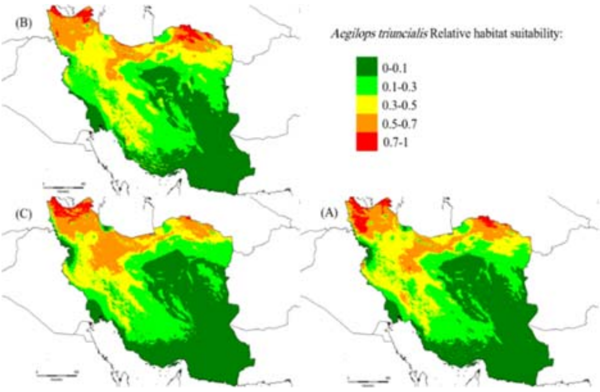

Figure 1) Relative habitat suitability of *Aegilops triuncialis* in Iran; The present (A); 2040 (B); 2070 (C); Colors represent the suitability percent and red color indicates the most suitable areas.

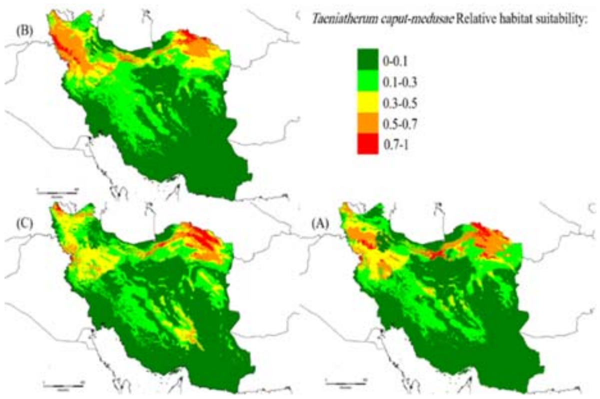

Figure 2) Relative habitat suitability of *Taeniatherum caput-medusae* in Iran; The present (A); 2040 (B); 2070 (C); Colors represent the suitability percent and red color indicates the most suitable areas.

Discussion

The studied species (*T. caput-medusae* and *A. triuncialis*) are considered as highly invasive species in Europe and especially in the USA [6, 10, 26]. In Iran, these species are present as native, but they play the same role in these native areas as in their exotic range [13]. In the present study, the present distribution range of these species was investigated, and then it was predicted for the future based on a climate change scenario. The mean temperature of the coldest quarter (Bio11) had the highest contribution to the distribution of these two species. Both species have winter growth and their germination begins in autumn. The vernalization period plays a crucial rule in their establishment.

At the present time, there is a high occurrence probability of the *A. triuncialis* in the lower and mid-elevations of northern Iran including its northeast, and Hyrcanian regions, with the exception of the western coasts of Caspian Sea, and northwestern Iran. Moreover, the presence of this species in Iran can be observed in the central parts near the Zagros Mountains. There is also a favorable condition for the presence of this species in the southern slopes of the Zagros Mountains (Figure 1-A).

In 2040, areas of northeastern Iran will be the most suitable areas for this species. However, northwestern regions of Iran will be less favorable for the plant, compared to the current distribution. Distribution of this species in the central parts of Iran will not be changed (Figure 1-B). In 2070, the lower and mid-elevations of northwest Iran will be strongly influenced by the presence of *A. triuncialis*. The probability of the presence of this species will be increased in the western parts of southern slopes of the Alborz Mountains. Results showed that climate change will not affect the ability of this species to grow in the upper elevations (Figure 1-C).

The modelling results for *T. caput-medusae* (Figure 2) showed that in the present, northeast, northwest, and some parts of central Iran are the most suitable regions for range expansion of this species. The southern coasts of the Caspian Sea, Hyrcanian region, are not suitable for growing this species so that this area has the lowest probability of the occurrence of this plant. This species is generally absent in the central parts of Iran with the exception of a few areas.

In 2040, the distribution range of this species in northeastern Iran will be more limited, and it will be seen to the upper elevations. In the southern slope of the Alborz Mountains in Iran, a shift to the western range and also to the highlands will be observed. The distribution range of this species will be further in northwestern Iran. The distribution of this species will not be changed in the southern and central parts of Iran. Furthermore, small areas of the Hyrcanian region might be invaded by this species. In 2070, in northeastern Iran, this species will reside predominantly on the upper elevations, as well as the condition for its presence in the highlands of eastern parts of Iran will be favorable. In the central parts of Iran, this species will be present in the high elevations of eastern Alborz. In northwestern regions of Iran, the distribution of this species will only be limited in the parts of lowlands near Iran's western borders. Generally, for 2070, this species will significantly be present in the central elevations of Iran. Mazangi *et al*. found that climate change affects the distribution range of endemic species [27]. Moreover, it was reported that climate change leads to the invasion of weed species to wheat fields in Iran [28].

According to the A1B climate change model, an increasing trend in temperature can be seen in all the years. An increase in temperature, especially in winter, causes the migration of medusahead to uplands that have a lower winter temperature. This can be considered as a serious threat to the conservation of alpine and subalpine ecosystems. The presence of this species can lead to the elimination of rare endemic species of alpine regions. The absence of this species in the very high elevations (more than 4200m a.s.l.) is due to the unfavorable conditions.

Considering the fact that both of these species are habitat threatening species [10], in comparison of the modelled distributions for the two, *A. triuncialis* is a more invading species for Iran's rangelands. *Taeniatherum caput-medusae* might have a smaller infestation range. However, it was reported that this species is among the noxious species that grows in high canopy cover [13]. Furthermore, in the present, to avoid the range expansion facilitation for both of the species it is recommend grazing exclusion in the invaded areas because either of the species is epizoochorous plant [13, 29]. For the future, based on findings of the present study, barbed goatgrass' distribution range will not change, instead, medusahead will invade the upper elevations and threaten the upper communities. Careful management should be undertaken for controlling and eliminating this species especially along grazed elevational gradients where the species lives.

Conclusion

This is the first study in which the potential distribution ranges of medusahead and barbed goatgrass was evaluated and also predicted using ENM in Iran. Results highlighted the susceptible areas for range expansion of those species in the present. Climate change will not affect the possible range of *A. triuncialis* in future. However, upper elevations might be invaded by *T. caput-medusae* in future. Based on the findings of the present study *A. triuncialis* is a more invading species compared to the other one. However, controlling *T. caput-medusae* to not invade upper elevations should be given a priory. Additional studies comparing the present and past distributions of *T. caput-medusae* along elevation gradients are necessary to be conducted in the future.

Acknowledgments: The authors thank Mrs. Aleme Mazangi for technical contribution to the modelling of the two species.
Ethical permissions: None declared by authors.
Conflict of interest: The authors have no conflict of interest.
Authors' Contributions: S.M.M.K devised the research plan and conducted the early analyses. M.B.E reanalyzed the data, prepared the figures and wrote the first draft. The final draft is approved by all of the authors.
Funding/Support: The authors received no specific funding.

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