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Modeling the richness and spatial distribution of the wild relatives of Iranian pears (*Pyrus* L.) for conservation management

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The preservation of the genetic resources of crop wild relatives (CWRs) is crucial for food production systems and is considered a vital measure for global agricultural health and food security. The identification of potential areas where CWRs can thrive is one of the first steps towards their conservation. In this study, we used a maximum entropy model (MaxEnt) to determine the habitat suitability of seven wild relatives of pears (*Pyrus* L.) for the first time. We aimed to identify high-priority areas for conservation and determine the hotspots for rich biodiversity in Iran. The study showed excellent predictive performance for all species studied (AUC value ≥ 90). The soil depth, solar radiation, minimum temperature of the coldest month (Bio6), and precipitation of the wettest quarter (Bio16) were the main environmental factors that influenced the habitat suitability of all seven species, according to permutation importance. The projected maps revealed that *P. elaeagnifolia* had the largest suitable habitat area, while *P. glabra* had the lowest. The results also showed that less than 5% of the suitable habitats for these seven species were in protected areas. This research highlights the need for national preservation policies and the development of cultivation and rehabilitation strategies for these threatened species.

Keywords Food insecurity, Rosaceae, MaxEnt, Species distribution modeling, Conservation

Biodiversity protection plays an important role in food production systems and is considered one of the most important measures of the world's agricultural health and food security[1]. Globally, the increasing loss of biodiversity and ecosystem services due to habitat destruction, over-harvesting, climate change, pollution, and invasive species has exacerbated food insecurity[2]. Planet warming and climate shocks are one of the most important factors in the loss of biodiversity and will lead to a decrease in food security[3]. The latest assessments of the Intergovernmental Panel on Climate Change[4] have reported the negative impacts of climate change on biodiversity loss worldwide. According to the IPCC Sixth Assessment Report, climate change has caused a 25% decline in agricultural production worldwide between 1961 and 2006. The report warns that the negative impact of climate change on crops will be even more severe in the years to come. This will lead to a widespread deterioration of agricultural products and increase the risk of food insecurity[4]. There are various ways to protect biodiversity and enhance food security, and one of them is through the use of Crop Wild Relatives (CWRs)[5]. These are important elements of biodiversity that have provided crucial agronomic traits for crop improvement, including the breeding of new climate-resilient crops or new drought- and pest-resistant plants, and can contribute to the improvement of global food security[6,7]. To preserve precious genetic resources and the continued evolution of their key agronomic traits, it is crucial to focus on in situ conservation[8]. Unfortunately, this important step is being neglected, as highlighted by Ref.[3]. To ensure the conservation of these valuable plant species and to improve crop efforts, it is important to identify the potential geographic distributions of CWRs and their species richness hotspots.

Species Distribution Modeling (SDM) is a valuable tool for planning in situ conservation[9,10]. SDMs help in identifying potential distribution patterns of species and the environmental factors that play a significant role in their distribution[11–13]. It also helps in mapping species richness and diversity hotspots and estimating the

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effectiveness of protected areas in safeguarding target taxa[14–16]. Currently, researchers worldwide are employing these models to identify conservation priorities of crop wild relatives (CWR) under existing and future climate conditions[17]. Some of the recent studies that use SDMs to prioritize CWR conservation include[18,19]. For example, predicted the impact of climate change on the potential distribution of 214 CWRs in the Netherlands using SDMs to determine conservation priority[20]. Using the maximum entropy (MaxEnt) approach to investigate the effects of climate change on the global distribution of two wild relatives of domesticated peas[21]. Modeled the potential climatic niches of wheat's wild relatives for food security management and biodiversity conservation in Iran[22].

Pears are a common fruit that grows in temperate climates. They have a pleasant taste and are highly nutritious and medicinal[23]. They are consumed all over the world and have a long history of cultivation that dates back 3000 years[24]. Homer's epic poem from the ninth century BC mentions pears as "a gift from the gods" in the garden of Alcinöus[25]. There are currently 3000 known varieties of pears grown worldwide, which are divided into two main groups: European pears (*P. communis* L.) and Asian pears (*P. pyrifolia* Nakai). According to Ref.[26], there are 26 wild relatives of pears worldwide, and identifying their diversity centers could help preserve these unique genetic resources. In Iran, the pear genus (*Pyrus* L.) consists of seven important CWRs, namely *P. syriaca* Boiss., *P. glabra* Boiss., *P. elaeagnifolia* Pall., *P. pashia* Buch.-Ham. ex D. Don., *P. communis* L., *P. salicifolia* Pall., and *P. turcomanica* Maleev. The species of *P. syriaca*, *P. glabra*, P. *elaeagnifolia*, *P. salicifolia*, and *P. turcomanica* belong to the secondary gene pool (GP2) of the European pears, while *P. communis* belongs to the primary gene pool (GP1) of this taxon. Additionally, *P. pashia* belongs to the secondary gene pool (GP2) of Asian pears. It has been found that ecological and conservation studies on pear wild-related species are few[27]. Our review of existing literature indicates that there are no studies on the use of SDMs to determine their potential distribution and the environmental factors that affect them. This study aims to contribute to the United Nations Sustainable Development Goals (SDGs) by identifying the potential distribution of pear wild-related species, and protecting and restoring their habitats to prevent the loss of their diversity. This aligns with SDG 15 (Life on land) and can also help achieve food security in Iran, which is in line with SDG 2 (Zero Hunger)[28]. In this study, we investigate the potential distribution patterns of seven pear CWRs in Iran using SDM. We aim to (1) identify the potential habitat suitability of these species, (2) determine the environmental factors that affect their distribution, (3) predict the potential centers of species richness, and (4) assess the overlap between suitable habitats for pear CWRs and protected areas in Iran to prioritize conservation strategies.

Materials and methods

Introduction of the studied species

Pyrus syriaca is mostly found in the Zagros Mountains and southwestern Asia[29]. It is a deciduous tree that grows up to 13 m high, has a broad crown, and has leaves that are obovate, ovate-lanceolate to lanceolate in shape[29]. The tree produces pomes that are pyriform to globose[29]. These fruits are edible and widely consumed by local communities[30–33]. The seeds of *P. syriaca*, both raw and cooked, have a calming effect and are used to treat migraines[31,33,34]. In addition, the fruits, leaves, and bark are used to treat stomachache, constipation, obesity, and kidney and heart failures[33,35,36]. This tree is cultivated because of its tasty, large, and fleshy fruits, and is used as a suitable rootstock for pear cultivars in regions with unfavorable precipitation conditions in Middle Eastern countries, where rainfall mostly occurs in specific months[37,38]. Molecular and experimental studies have demonstrated that wild populations of this species serve as fully compatible pollinators for pear cultivars[39].

Pyrus glabra is a species of wild pear that is found only in Iran. It grows in the marginal area of Quercus brantii Lindl. woodlands in the central Zagros region[29]. This tree usually grows to a height of 5–10 m and has elongated leaves that are ensiform-lanceolate to long elliptic in shape[29]. The fruits are globose to subglobose and are locally known as "Anchochek or Anchocheh"[40]. People not only eat these fruits as food but also use them to increase their libido and improve their body strength[33,40–42]. In addition to its use as food, *P. glabra* is also used in traditional medicine. The bark and leaves of this tree are a great source of fiber and have been used to treat various ailments such as gout[33]. The oil extracted from its seeds is used to relieve pain and to manage headaches and kidney diseases[32,33,43,44].

Pyrus turcomanica is a tree that grows up to 15 m tall and is found only in the foothills of the Khorassan-Kopet Dagh Mountains and Central Asia[45]. It has a disjunct distribution in the south Transcaucasus as well. The leaves are linear-lanceolate or oblanceolate, and the fruits are globose to subpyriform[45]. The fruit is edible and has many uses, which is why the plant has been domesticated or used as a rootstock in other parts of Central Asia where it does not grow naturally[46].

Pyrus elaeagnifolia is a montane deciduous tree of wild pears distributed west and north Balkan Peninsula, Crimea, Turkey to west Iran[29]. It is a species up to 15 m tall, unarmed, or rarely armed, with broadly lanceolate, oblanceolate, sometimes oboval-oblong or subspatulate leaves, pomes pyriform to flattened-globose[29]. Several therapeutic and nutritional properties have been known of the plant[47]. The boiled fruits and leaves have known detoxification properties and are used to enhance the rate of elimination of snake venom[48]. The fruit possesses many characteristics such as anti-diarrhea, anti-inflammatory, anti-diuretic, anti-hypertensives and anti-diabetic properties, treatment of poisonous snake bite and cardiovascular disease[48–56]. The cultivated *Pyrus* species are often grafted on *P. elaeagnifolia* rootstocks due to their good compatible traits[48,57].

The *P. salicifolia* tree is commonly found in northwest Iran, east Turkey, south Azerbaijan, and Caucasus[29]. This tree reaches heights of 3–10 m and is covered in spines. Its leaves are ensiform-linear to oblanceolate and its fruits are either globose or pyriform[29]. The *P. salicifolia* tree is known for its high drought tolerance, which makes it a popular choice for rootstocks in cultivated trees and decorative purposes[58–60].

Pyrus pashia is a species of tree that grows in the mountains of East Asia, Pakistan, Afghanistan, and northeast Iran[45]. It can grow up to 12 m tall and is often covered in thorns[45]. Its leaves are ovate-lanceolate, rarely elliptic, and its fruits have white or brown dots, and are sub globose or globose in shape[45]. This tree is commonly used as a rootstock for grafting cultivated pear varieties[23]. The fruits are edible and are also used in traditional medicine to treat various illnesses[23]. The leaves are also used in folk medicine for cosmetic purposes, such as a skin softener[23].

Pyrus communis is a tree species that is naturally found in the Mediterranean region of Europe and West Asia, but it is widely cultivated around the world[29]. The tree can grow up to a height of 3-30m and has suborbicular or oval-shaped leaves. The fruit of the tree is pyriform or sub globose in shape[29]. Today, this plant has high economic and nutritional significance and is among the most important fruits produced in the world, ranking as the fifth most produced fruit on Earth[61]. *P. communis*, along with *P. pyrifolia*, is cultivated on more land area than any other domesticated pear species[61]. The species has been known for its medicinal properties for a long time, with some of its medicinal benefits including anti-cancer, anti-osteoporosis, anti-inflammatory, anti-mutagenic, anti-hyperlipidemic, antimicrobial, anti-obesity, cholesterol-lowering, wound healing, skin whitening, anti-diabetic, cardio-protective, and respiratory protective[61,62].

Occurrence records of pear CWRs

We collected data on the occurrence of 7 pear CWR in Iran from multiple sources, including our field investigations conducted between 2012 to 2021, botanical distribution records from Flora of Iran[29], Flora Iranica[63], and previous articles[45,64]. We gathered a total of 178 occurrences of the target species. The modeling process employed 144 occurrence records after removing all species' distribution information within at least 1 km (Fig. 1 and Supplementary 1).

Predictive environmental variables

In our research, we selected 9 environmental factors that are known to influence the distribution of species. These factors include topography (elevation), soil properties (soil depth, sand, silt, and clay content), climate (BIO12 = annual precipitation, BIO6 = min temperature of the coldest month, and BIO16 = precipitation of the wettest quarter), and solar radiation. We downloaded climate data from the Chelsa database (http://chelsa-climate.org) at a resolution of 30 s, which is roughly equivalent to 1 square kilometer. We obtained topographic data and solar radiation data from layers available at www.worldgrids.org at the same resolution. Additionally, we acquired soil data from the Global Soil Grids database (SoilGridsTM) (https://www.isric.org) at a resolution of 30 s. Additionally, the variance inflation factor (VIF) was used to avoid collinearity among variables. Highly correlated variables (VIF < 10) were eliminated using the "usdm" package[65]. Finally, 7 predictive variables remain for model projection and sand and BIO12 were removed (Table 2 and Supplementary 1).

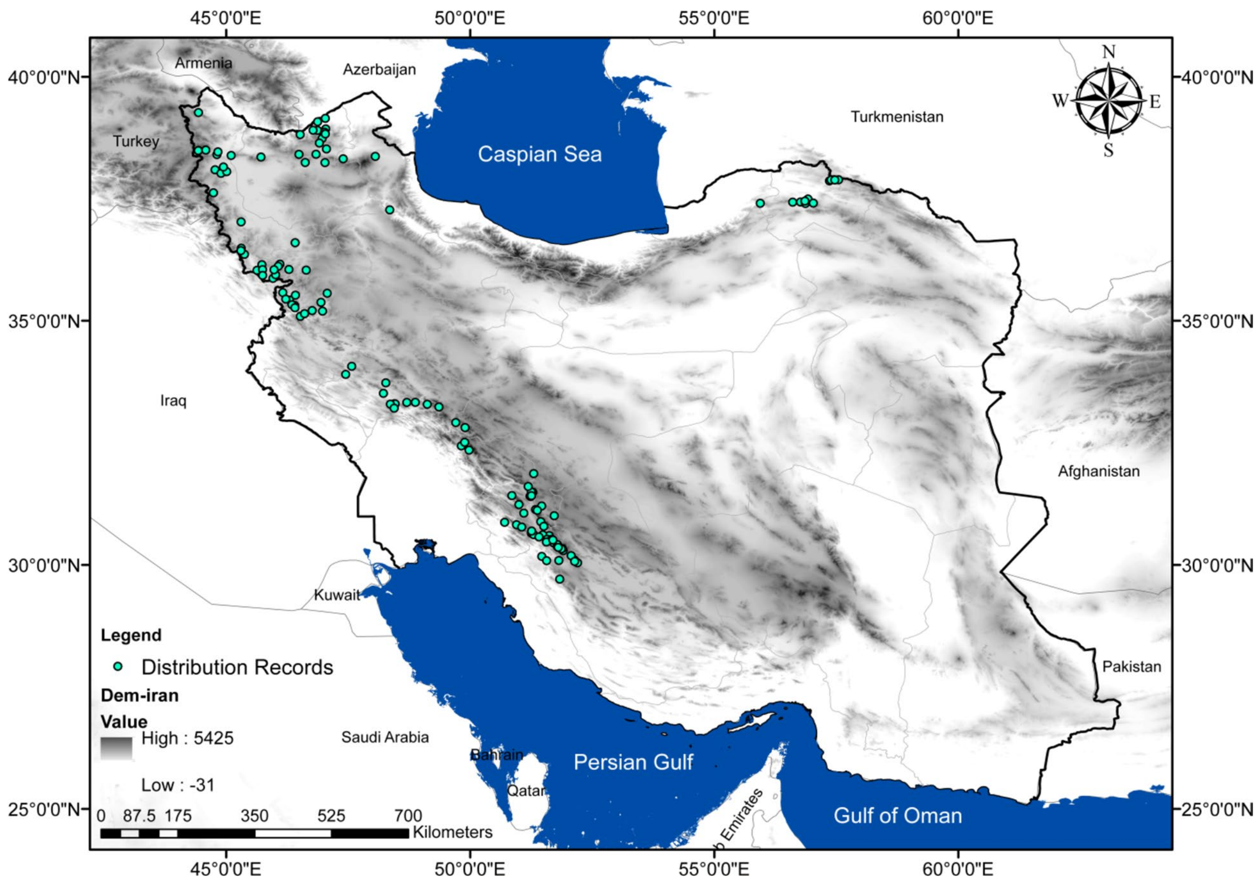

Figure 1. Occurrence records of Iranian pear CWRs (black dots) and topographic map of Iran (ArcGIS 10.3 software).

Species distribution modeling

In this study, we simulated potential species distribution ranges using the maximum entropy approach in MaxEnt v3.4.4k[66]. The MaxEnt parameters' settings included cross-validation replicated run type, 10 replicates, a maximum number of iterations of 1000, a convergence threshold of 0.0001, and 10,000 background points. The permutation importance was considered to identify the key variables for MaxEnt models[67]. The area under the receiver operator curve (AUC) of the receiver operating characteristic (ROC) curve was used to assess the accuracy of the modeling results[68,69]. AUC is a threshold-independent measure of model performance, and an AUC value of 0.5 indicates random prediction In this study, we used MaxEnt v3.4.4k[66] to simulate the potential distribution ranges of species. The MaxEnt parameters were configured with the cross-validation replicated run type, 10 replicates, a maximum of 1000 iterations, a convergence threshold of 0.0001, and 10,000 background points. To identify the critical variables for MaxEnt models, we used permutation importance[67]. The accuracy of the modeling results was evaluated using the area under the receiver operator curve (AUC) of the receiver operating characteristic (ROC) curve[68,69]. AUC is a threshold-independent measure of model performance, and a value of 0.5 indicates random prediction performance, while values near 1.0 indicate better model performance[70].

Coverage of existing protected areas

We analyzed the extent to which currently protected areas cover habitats suitable for each species, to determine the conservation priorities for them. We calculated the coverage of existing protected areas using the spatialEco package v1.3-7 in the R 4.2.1 environment[71]. This information is crucial in identifying areas where conservation efforts should be focused for the studied species.

Predicting species richness

To estimate species richness in Iran, we first converted habitat suitability models to binary rasters using a 10-percentile training presence logistic threshold[66,72]. Then, all binary raster layers were summed using the raster calculator function of ArcGIS 10.3, and a richness map was generated (Figs. 3, 4, 5).In addition, in this study, we have also used ArcGIS 10.3 software to prepare Fig. 1.

Results

Model evaluation and variable importance

The results of potential habitat suitability modeling for all 7 studied species showed a high level of predictive accuracy, as demonstrated in Table 1 and Supplementary 1. By analyzing the permutation importance of individual variables used in the modeling process, we found that soil depth, solar radiation, BIO6 (minimum temperature of the coldest month), and BIO16 (precipitation of the wettest quarter) were the key environmental factors influencing the habitat suitability of all 7 species (Table 2 and Supplementary 1). Soil depth, in particular, played a major role in determining the potential distributions of *P. communis*, *P. pashia*, and *P. turcomanica* (Table 2 and Fig. 2). The distribution of *P. salicifolia* and *P. glabra*, as well as *P. turcomanica* were significantly impacted by solar radiation, while *P. syriaca* was most affected by the precipitation during the wettest quarter (Table 2 and Fig. 2). In addition, the minimum temperature of the coldest month is the strongest predictor of *P. elaeagnifolia*'s habitat suitability in Iran.

Current potential suitable habitat for pear CWRs

According to the MaxEnt model, *P. elaeagnifolia* had the largest suitable habitat area, covering 229,849.7 km^2 (41%), while *P. glabra* had the smallest suitable habitat area, covering only 20,653.13 km^2 (4%) (Fig. 3). The suitable habitats for *P. communis* and *P. syriaca* were primarily located in the western regions of Iran, specifically in the Kordestan and Kermanshah provinces and the southern parts of West Azarbaijan province (Fig. 3). The high-suitability habitats of *P. elaeagnifolia* were mainly distributed in the Zagrosian, Alborzian, and Azerbaijan Plateau ecosystems (Fig. 3). The model predicted that highly suitable areas for *P. glabra* were concentrated in Kohgiluyeh and Boyer-Ahmad province, as well as scattered regions of Fars and Chaharmahal and Bakhtiari provinces. *P. pashia* and *P. turcomanica* were mainly distributed in the southwestern parts of Golestan province and very scattered areas in North Khorasan and Razavi Khorasan provinces (Fig. 3). *P. salicifolia* was mainly distributed in some parts of the Gilan, Ardebil, and East Azarbaijan provinces (Fig. 3).

Coverage of existing protected areas

According to the analysis of the coverage of the current protected areas, it was found that only a small percentage of suitable habitats for the seven species were present in the protected areas (less than 5%) as shown in Fig. 4. The estimated coverage of protected areas for suitable habitat of *P. glabra* was 500 km^2 (2.42%), for *P. communis* it was 656 km^2 (1.93%), for *P. syriaca* it was 485 km^2 (1.17%), for *P. salicifolia* it was 595 km^2 (0.92%), for *P. pashia* it was 606 km^2 (0.82%), for *P. turcomanica* it was 379 km^2 (0.41%), and for *P. elaeagnifolia* it was 776 km^2 (0.33%), as shown in (Fig. 4).

Estimated species richness

According to the richness map, the Azerbaijan Plateau situated in northwestern Iran is home to the highest number of species (6 species), as indicated in Fig. 5. However, habitats such as Alborzian and Zagrosian, along with Kopet Dagh mountains, have only 0–3 species. It has been observed that the distribution of pear Crop Wild Relatives (CWRs) in Iran follows a south-to-north pattern. The highest species richness is found in the higher northern latitudes. The map also suggests that vast areas of central, eastern, southern, and small western Iran do not have many species and are therefore not considered suitable habitats for the species in question (Fig. 5).

Discussion

This study provides the first report on the potential habitat suitability of seven wild pear species and their potential richness hotspots in Iran. The results of the study suggest that the potential habitats of the studied species are located in mountain ecosystems in Iran, including Zagros, Alborz, Kopet Dagh-Khorassan, and Azerbaijan Plateau. Previous studies have also reported these ecosystems as the major centers of diversity and the main areas of endemism of many plant species in Iran[73–79]. Atropatan Province, located in the Azerbaijan Plateau, was found to have the largest number of wild pear species. This province is one of the main plant diversity and speciation centers in the Irano-Turanian region, with exceptional topographic heterogeneity and the presence of two different climatic zones[80–84]. It is also an area of endemism and speciation in Iran, influenced by the Mediterranean climate[85]. The province is located at the crossing point of the Alborz, the Zagros, and the Caucasus Mountain ranges and incorporates exceptionally tall mountains that harbor numerous species[86]. These unique environmental factors provide special habitats for numerous plants and animal taxa in this phytogeographical province[79]. The distribution and abundance of various plant and animal species typically increase with latitude, a concept known as the latitudinal Rapoport's rule[87–91]. This rule also appears to apply to the richness and distribution of Iranian pear wild relatives and other plant groups in Iran including montane/Alpine plants of the Irano-Turanian region[92], four families of flowering plants[93], Iranian endemic monocots[78], *Acantholimon* Boiss.[81], *Onosma* L.[82].

Our study has revealed that sunlight is a crucial environmental factor that determines the distribution of most of the species we studied. Pears are a type of light-loving plant that is typically found growing on the fringes of oak forests or in scattered vegetation across the landscape[94,95]. Previous ecological research on wild pear species has shown that they thrive in sunny locations and can only survive when there is sufficient light[94,96–100]. In line with these findings,[100] observed that pear tree species tend to avoid shady areas from an early age and may not survive without minimal light sources[101]. Our field observations have confirmed that sunlight plays an essential role in the distribution of wild pear species in Iran. Another critical variable that affects the distribution of these species is the minimum temperature or winter minimum temperature (Bio6). BIO6 is an important factor in the physiological functions of plants. Deciduous fruit trees and shrubs, such as the rose family, thrive in temperate climates and have specific heating and cooling requirements that must be met[102]. All *Pyrus* species require a chilling period to break bud endodormancy and initiate the subsequent phenological development process, including fruit yield[103–106]. Deviation from optimal temperature values can cause pear blooms to freeze, leading to adverse

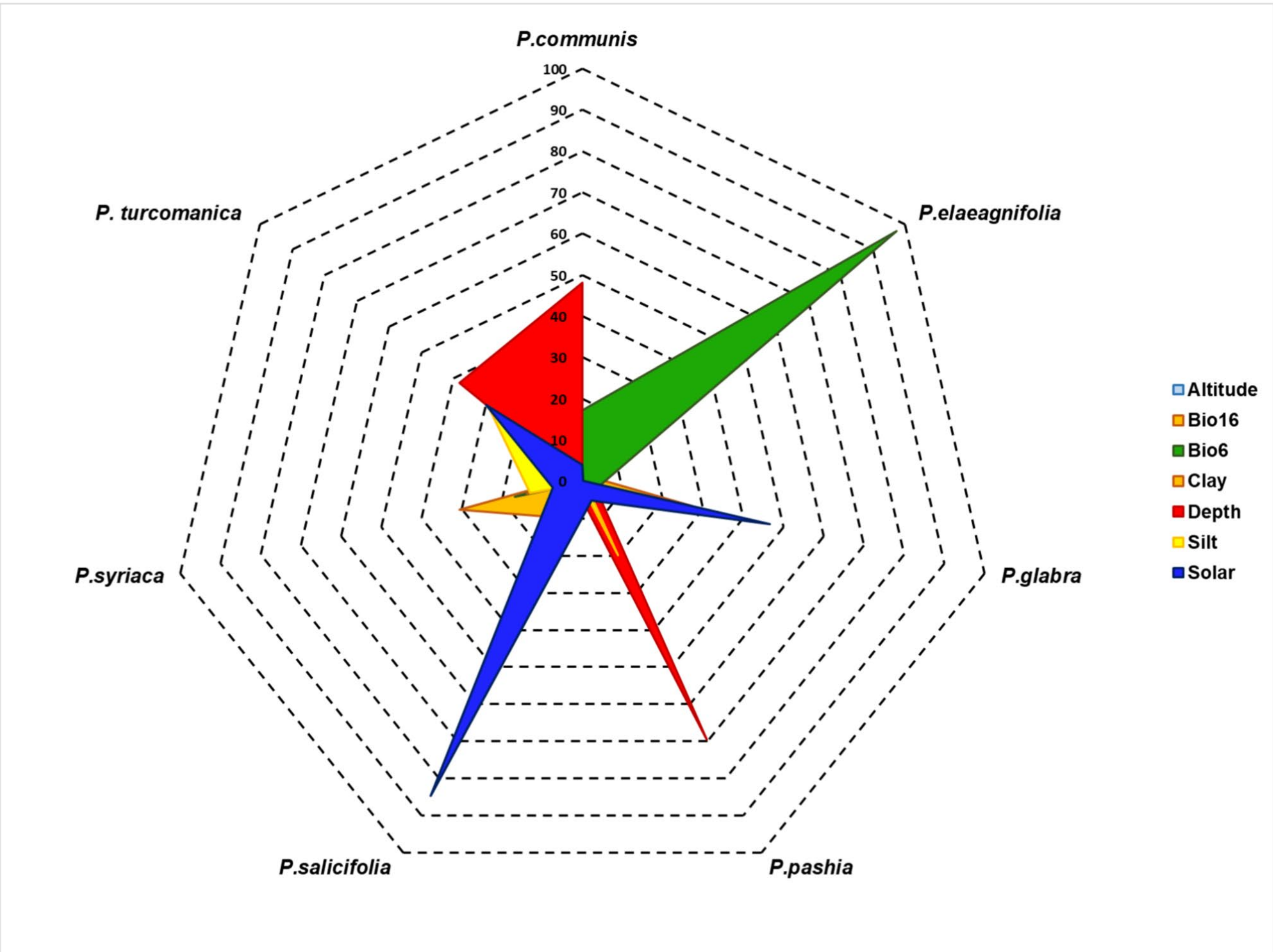

Figure 2. Mean importance of the variables according to the percentage of permutation importance.

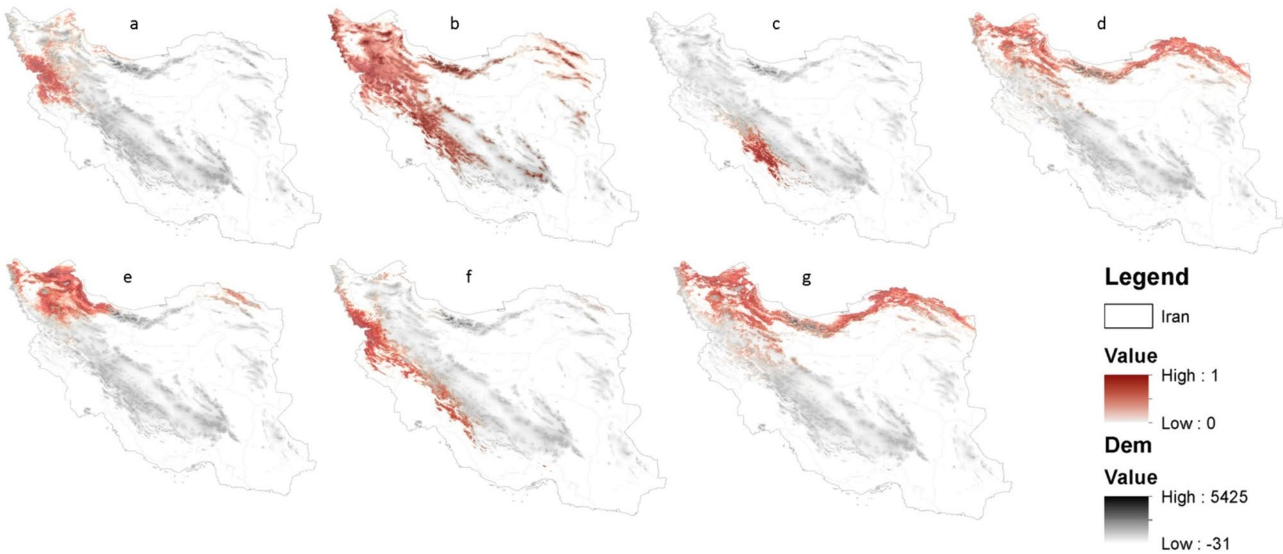

Figure 3. Predicted suitable distribution habitats of 7 pear CWRs in Iran based on the MaxEnt model. (**A**) *P. communis*, (**B**) *P. elaeagnifolia*, (**C**) *P. glabra*, (**D**) *P. pashia*, (**E**) *P. salicifolia*, (**F**) *P. syriaca*, (**G**) *P. turcomanica* (All binary raster layers were summed using the raster calculator function of ArcGIS 10.3).

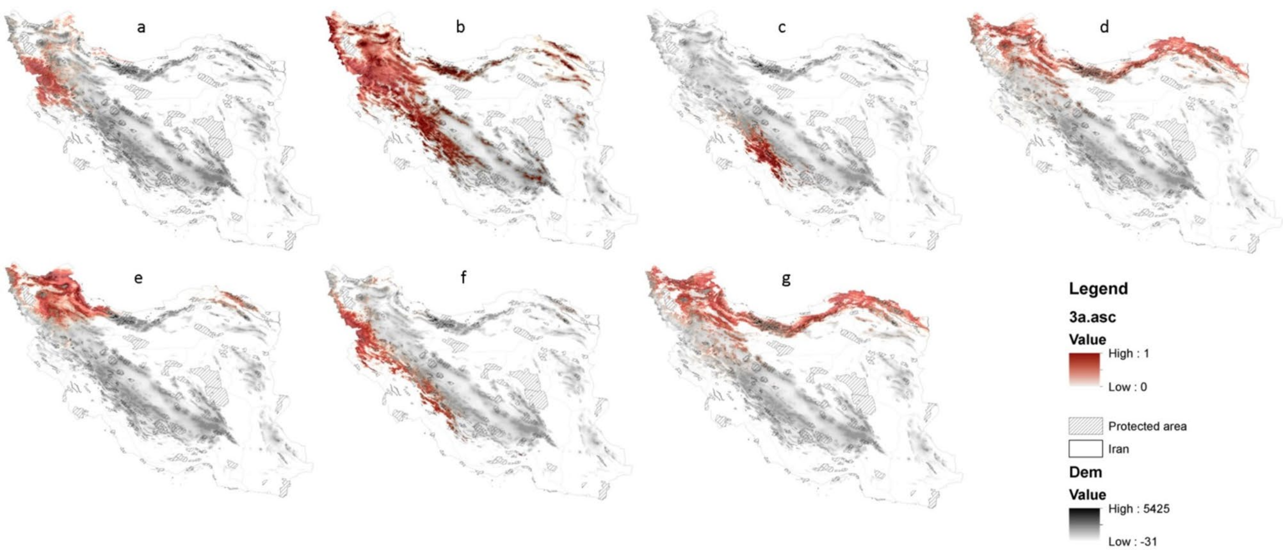

Figure 4. Predicted suitable distribution habitats of 7 pear CWRs in protected areas of Iran. (**A**) *P. communis*, (**B**) *P. elaeagnifolia*, (**C**) *P. glabra*, (**D**) *P. pashia*, (**E**) *P. salicifolia*, (**F**) *P. syriaca*, (**G**) *P. turcomanica* (All binary raster layers were summed using the raster calculator function of ArcGIS 10.3).

effects on their yield and distribution[107]. This is why the minimum temperature of the coldest month is considered a key variable in the potential distribution of pears. Winter coldness is one of the two major determinants of the latitude diversity gradient of Northern Hemisphere plant species[108,109]. Environmental factors, such as winter coldness, play a major role in the abundance and diversity of tree species in North America[110], which is similar to the results of our study. The distribution of pear trees seems to be associated with forested areas found in wet conditions. Wild pear trees tend to grow around deciduous forest areas, which have a wetter climate and relatively fertile soils[101]. Winter precipitation, the third key variable, not only affects the physiological functions of woody species, such as yield and fruit quality but also influences plant development in the following growing season[111]. Several studies have been conducted in different regions, including the western United States[112], the southwestern United States[113], eastern England[114], and the Karakoram in northern Pakistan[115]. These studies have emphasized the significance of winter rainfall for the growth and development of tree species. The model results indicate that soil parameters play a crucial role in the distribution of the studied species. Wild pears are usually found growing in shallow, heavy clay, nutrient-rich soils with lower soil moisture, particularly on the edge of xeric forests[116–118]. Therefore, it seems reasonable to consider soil depth as a key factor in determining the distribution of the studied species. Soil depth is crucial for providing mechanical support to shrubs and trees and plays a significant role in water access and nutrient distribution in the soil[119]. This, in turn, affects the growth

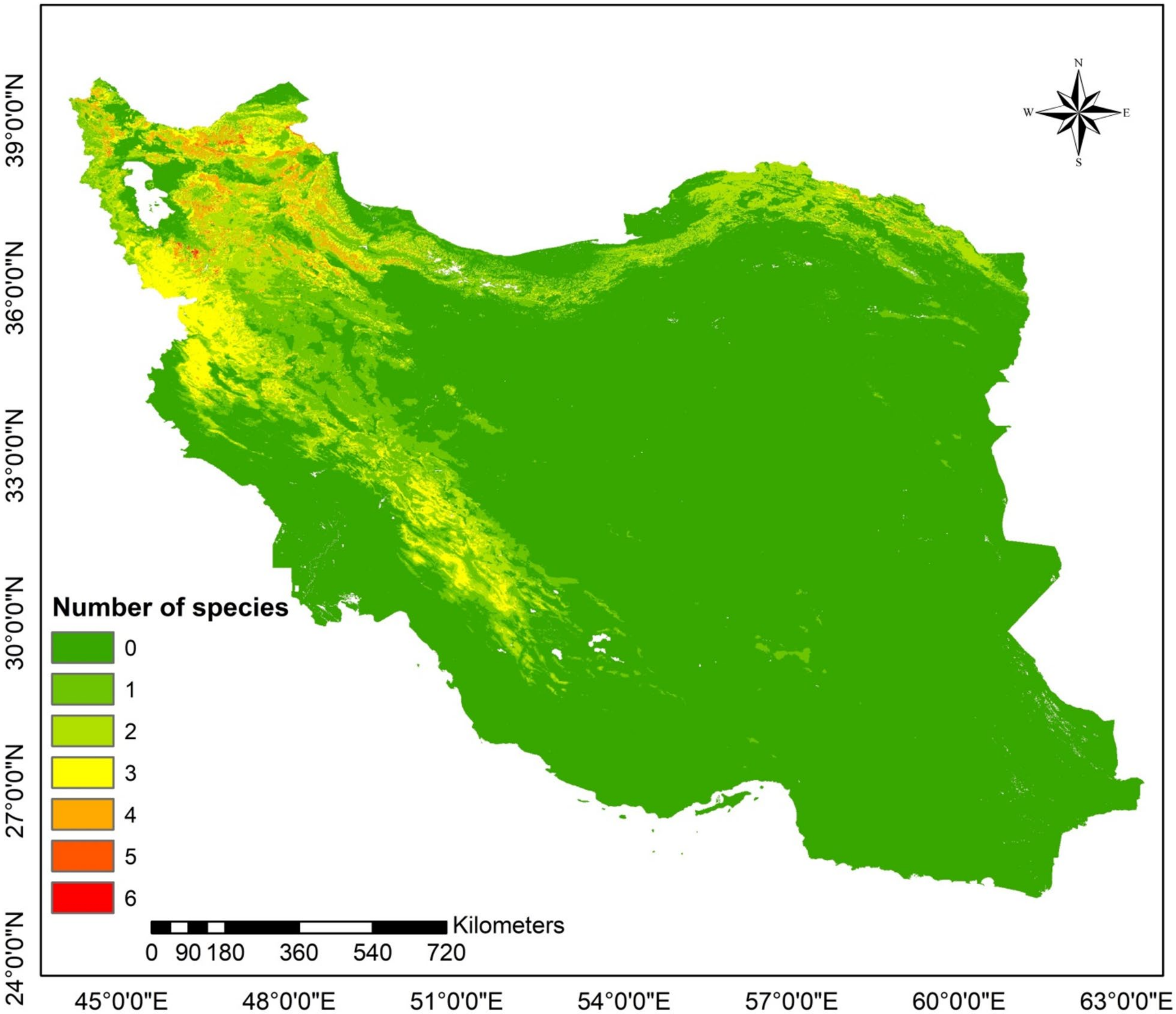

Figure 5. Potential richness map of pear CWRs in Iran (Using ArcGIS 10.3 software).

Species	Mean AUC	SD of AUC
P. communis L	0.987	0.009
P. elaeagnifolia Pall	0.905	0.038
P. glabra Boiss	0.986	0.011
P. pashia Buch.Ham ex_D. Don	0.976	0.019
P. salicifolia Pall	0.962	0.028
P. syriaca Boiss	0.964	0.019
P. turcomanica Maleev	0.97	0.016

Table 1. The results of the accuracy evaluation of model prediction based on AUC values.

and distribution of plant species[119]. Recently, reported the significant role of this environmental variable in the geographical distribution of some Iranian plant species, such as *Allium* spp.[120].

On the other hand, our study revealed that less than 5% of the favorable habitats of the studied species were located in the protected areas of Iran. Various studies show that about 29% of the world's flora is endangered and about 70% of the wild relatives of agricultural crops are under various threats[121]. Also, species distribution models have suggested that major agricultural products will decrease in response to future climate changes[122] In addition, these models suggest that many CWRs in the world, such as peanut (*Arachis*), potato (*Solanum*) and

Species	Variable						
	Altitude	Bio16	Bio6	Clay	Soil depth	Silt	Solar
	Permutation importance (%)						
P. communis	0	9.9	17.2	18.1	48.1	2.9	3.9
P. elaeagnifolia	0.8	1.9	97.3	0	0	0	0.1
P. glabra	14.9	27.1	4.4	3.7	2.9	0.5	46.5
P. pashia	0	2.7	0.9	2.1	69.4	19.9	5.1
P. salicifolia	1.7	9.9	0.4	0.1	2.5	0.7	84.7
P. syriaca	17.9	30.6	16.9	13.7	0.5	13.1	7.3
P. turcomanica	0.1	1.7	1.1	0.1	38.1	29.2	29.8

Table 2. Percentage of permutation importance for each variable.

cowpea (*Vigna*)[123], wheat (*Triticum*)[21], and 204 CWRs of Norway[124], are sensitive and fragile to future climate changes and will be highly vulnerable.

Conclusion

This study used the MaxEnt model as a tool to determine high-priority areas for monitoring and developing national preservation policies among seven pear crop wild relatives in Iran. Among the studied species *P. glabra* is at high risk of extinction, as it has the lowest distribution among the studied species. It only exists in the central Zagros ecosystems, a biodiversity hotspot in Iran[27,125]. This ecosystem is home to many plant and animal species, including wild relatives of economically important agricultural products[126]. However, rapid changes in land use, overgrazing, and unmanaged logging have caused irreversible damage, leading to the loss of many species[27,125]. Therefore, planning for the protection of suitable habitats for this species is very essential. Considering the limited distribution of this species, it seems that it is a fragile and vulnerable species and unable to adapt to future climate changes. Therefore, ex situ and in situ, conservation actions are needed to prevent its extinction. We believe that the potential habitats for these species that were identified should be included in the country's conservation priorities. We suggest that a complementary approach of in situ conservation as a dynamic mode of germplasm conservation and ex-situ conservation (e.g. gene banks, seed banks, pollen, and tissue storage) be accomplished to protect these taxa. It is also very necessary to raise the awareness of local people about these trees during an educational program and protect them in the form of on-site/in situ habitat and mostly a "natural reserve" form to protect the remaining diversity in the habitat and facilitate the continuation of the evolution of their genes. It has been predicted that climate change will greatly affect the distribution of plant species in the future. Therefore, we suggest that species distribution models be used to study the effects of climate change on the distribution of the species that have been studied. This will help in protecting these species. We hope that the relevant experts will domesticate these valuable plant species to ensure food security in the near future. Because biodiversity conservation and food security are closely linked, the International Union for Conservation of Nature (IUCN) has placed a high priority on protecting and sustainably using ecosystems[127]. Therefore, it is crucial that urgent action be taken at the national level to protect the suitable habitats of these valuable plant species due to the increase of destructive human activities in recent decades in Iran, climate change, deforestation, drought, and the spread of pests and diseases. This study's results can be an effective step in preventing the reduction of their diversity and reducing food insecurity in Iran.

Data availability

Datasets analyzed during the current study are available on Figshare as https://figshare.com/articles/dataset/Supplementary_1/25752426.

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F.K.: Writing – original draft, Conceptualization, Data curation, Investigation, Methodology, Validation, Visualization. F.K. and Z.S and A.Z.: Writing reviewing & editing, Data curation F.K. and Z.S.: Software, Formal analysis.

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Competing interests

The authors declare no competing interests.

Additional information

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