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CONSERVATION PRIORITIES AND DISTRIBUTION PATTERNS OF THE GENUS PSEUDOPODOSPERMUM IN IRAN

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The present study provides an overview of geographic distribution patterns as well as the conservation priorities assessment of the genus *Pseudopodospermum* in Iran, using a GIS framework. A set of geographic distribution data was compiled through field studies, reviews of Flora Iranica, Flora of Iran, and examination of the herbarium specimens deposited at various herbaria. The geographic distribution mappings of the genus were analyzed using ArcView and DIVA-GIS software. High species richness was observed in Kurdo-Zagrosian Province, followed by Fars-Kerman, Atropatanean, and Northern Khorasan Provinces in Irano-Turanian phytogeographical region. Regarding our results, it could be concluded that effective conservation management in Kurdo-Zagrosian Province would lead to protecting a high percentage of *Pseudopodospermum* species against the threat of extinction.

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Keywords: GIS framework; species richness; Kurdo-Zagrosian Province; conservation priorities.

اولویت های حفاظتی و پراکندگی جغرافیایی جنس Pseudopodospermum در ایران

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مطالعه حاضر به بررسی الگوهای پراکنش جغرافیایی و ارزیابی اولویت های حفاظتی جنس Pseudopodospermum در ایران با استفاده از سامانه GIS می پردازد. مجموعه داده های جغرافیایی از طریق مطالعات میدانی، جمع‌آوری داده‌های موجود در فلور ایرانیکا، فلور ایران و همچنین بررسی نمونه‌های هرباریومی متعدد گردآوری شد. پراکنش جغرافیایی این جنس با استفاده از نرم افزارهای ArcView و DIVA-GIS مورد تجزیه و تحلیل قرار گرفت. غنای گونه‌ای بالایی در پروانس‌های کرد–زاگرسی و پس از آن در فارس–کرمان، آتروپاتن و خراسان شمالی از ناحیه ایران–تورانی مشاهده شد. مقایسه نتایج حاصل از آنالیز تکمیلی نشان داد که مدیریت حفاظتی صحیح در پروانس کرد–زاگرسی منجر به حفاظت درصد بالایی از گونه های جنس Pseudopodospermum در برابر خطر انقراض می‌شود.

INTRODUCTION

Many conservation biologists have focused on mapping biodiversity hotspots (Reid 1998, Meyer & al. 2000), centers of endemism (Jetz & al. 2004) as well as diversity centers of rare and endangered taxa (Dobson & al. 1997, Prendergast & al. 1993). Recently climate change, drought, and the destruction of ecosystems have intensified the requirements of

compiling biodiversity fundamental data for conservation management (Mutke & Barthlott 2005). The International Union for Conservation of Nature (IUCN) is increasingly undertaking national and regional Red List assessments and collaborating on national Red List projects to incorporate their data into the global IUCN Red List (IUCN 2022). Relevant to this issue, a series of regional red lists of threatened species have been produced which provided scientifically based information on the conservation status of species particularly endemic and rare species, within a political management unit (For example Iran: Jalili and Jamzad 1999). Accordingly, the databases comprising the information on plant biodiversity and collection data have been used to set priorities on small to large scales (Barthlott & al. 1996, Mehrabian & al. 2021). The advent of the Geographic Information System (GIS) has made large-scale studies possible, in which a large georeferenced database of locations would be analyzed and variables such as species richness can be mapped on a grid, leading to identifying the species diversity hotspots (Crisp & al. 2001).

The flora of Iran with more than 7,800 plant taxa has been considered a center of diversity for vascular plants in the world (Assadi & al. 1988–2018, Kier & al. 2005). A wide range of climatic conditions and geomorphological complexities have led Iran to have high species richness and also become a prominent zone of endemism (Zohary 1973, Noroozi & al. 2016). Here we provide an overview of geographic distribution mapping and conservation priorities assessments of the genus *Pseudopodospermum* (Lipsch. & Krasch.) Kuth. (Scorzonerinae, Cichorieae, Asteraceae) in Iran using a GIS framework.

With regards to the taxonomic history of this genus, *Pseuodopodospermum* was first described as a section within the genus *Scorzonera* L. by Lipschitz and Krascheninnikov (Lipschitz 1935), but later, Lipschitz (1964) changed its taxonomic rank to subgenus. This taxonomic concept was widely accepted in the Flora USSR (Lipschitz 1964), Flora Iranica (Rechinger 1977), and Flora of Iran (Safavi 2013). Recently, a taxonomic reassessment of the subtribe Scorzonerinae was performed by Zaika & al. (2020), based on morphological, carpological, and molecular phylogenetic information. They proposed a revised classification of the lineages within *Scorzonera* s.l. and represented that *Scorzonera* in its wide traditional sense was segregated into six lineages, while each lineage was accepted as a separate genus. One of these circumscribed genera is *Pseudopodospermum*. In our study, we followed the narrow circumscription of *Scorzonera* that recognized *Pseudopodospermum* at generic rank.

Morphologically, *Pseudopodospermum* species are perennial herbs, possessing tuberous roots, entire leaves with undulate margins (rarely pinnatifid leaves), and glabrous achenes with sculptured (muricate, tuberculate, verrucose, or denticulate) surfaces even with or without carpopodia (Zaika & al. 2020, Hatami & al. 2020). Besides being a source of feed for livestock, the tubers and fresh leaves of several species have been commonly used as medicinal plants in European and Asian herbal therapy for ages, or in some cases as valued vegetables in the green salad (Lendzion & al. 2021, Akkol & al. 2012, Nasseri & al. 2015). Geographically, the species are widespread in the temperate and subtropical regions of Eurasia and North Africa, with a high concentration of species in the Irano-Turanian and East Mediterranean Regions (Zaika & al. 2020). Depending on the last circumscription of this genus, it possessed approximately 41 species in the world, of which 14 are widespread in Iran (Rechinger 1977, Safavi 2013, Zaika & al. 2020, Hatami & al. 2022). Therefore, the flora of Iran has been considered one of the diversity centers for this genus. Despite the importance of this group in Iran, little attention has been paid to distribution patterns and diversity centers as well as the priority zones for the conservation of these valuable taxa in Iran. Therefore, the aims of the present study are: 1) providing the distribution pattern of *Pseudopodospermum* species and defining the regions with a high concentration of species diversity. 2) Exploring and subsequently identifying the regions with high priorities in the protection of *Pseudopodospermum* taxa in Iran and 3) Evaluating the conservation status of the species in order to find the taxa that are threatened with extinction.

MATERIALS AND METHODS

We prepared a comprehensive checklist of *Pseudopodospermum* species from different areas in Iran based on all available data. The plant taxonomic and distribution data were gathered from three main sources: I) Flora Iranica (Rechinger 1977) and Flora of Iran (Safavi 2013), which are the major taxonomic and nomenclatural references for this study. II) Examined herbarium specimens deposited in B, FMUH, HSHU, IRAN, JE, MIR, TARI, and W (herbarium codes according to Thiers 2022+). III) Geographic distribution data of plant specimens obtained from previous studies relevant to this genus (Safavi 2004, Safavi 2019, Hatami & al. 2020, Hatami & al. 2022). Most of the data sets didn't have

coordinates, thus, we used Google Earth ver. 5.1 (http://earth.google.com) to georeference the locations. All geographic coordinates were then subjected to an error-checking exercise using Mapinfo GIS Software. The final dataset used in this analysis contained 793 georeferenced entries for performing further geographic distribution analyses.

In our study, we provided the geographic occurrence of studied species in the world (obtained from the Cichorieae portal; Kilian 2009+), and also their phytogeographical distribution in Iran based on phytochorion limitations of Iran proposed by Assadi (2006). In accordance with Assadi's phytochoria, three regions and eight provinces were recognized for the flora of Iran: (1) Euro-Siberian Region [I: Hyrcanian Province]; (2) Irano-Turanian Region [II: Atropatanean Province], III: Northern Khorasan Province, IV: Kurdo-Zagrosian Province, V: Central Iran Province, VI: Northern Baluchistan Province, VII: Fars-Kerman Province]; and (3) Saharo-Sindian Region [VIII: Nubo-Sindian Province].

The conservation status of each taxon was also evaluated using the IUCN Red List categories and criteria at the regional scale (IUCN 2022), calculated by Kew GeoCAT (http://geocat.kew.org/; Bachman et al. 2011). The extent of occurrence (EOO) and area of occupancy (AOO) were calculated in GeoCAT using the georeferenced occurrence data for each species. Subsequently, both metrics were used to classify the threat status of species. Moreover, the index of species rarity (RI) in the study area was conducted based on Williams & al. (1996). The RI was calculated as the inverse of the number of cells with documented species throughout the target area following as RI= 1/Ci, where Ci is the number of grid cells. The distribution pattern of the genus was conducted in ArcView ver. 3.2 (ESRI 2000) and DIVA-GIS ver. 7.3. The ArcView was used to produce the shapefile map of the specimen localities, using data import tools that required latitude and longitude information. Then, the point data in the shapefile format was imported into DIVA-GIS software to create grid files, where each grid cell takes a value calculated based on the points within the cell. The number of observations and species richness was mapped using 10×10 km grid cells and the circular neighborhood option with a radius of 50 km. Calculations are made based not on the observations within each grid cell, but rather on the observation found within a circle with its center in the middle of each grid cell and on the specified radius (Cressie 1991). The circular neighborhood option is chosen for the analysis/point-to-grid/richness analysis tool in order to eliminate border effects caused by the assignation of the grid origin and to obtain results less sensitive to small changes in the coordinate data (Hijmans & Spooner 2001).

To investigate more aspects of distribution patterns of the genus, we performed a complementary analysis in DIVA-GIS using the point-to-grid/reserve selection option based on the algorithm described by Rebelo (1994) and Rebelo and Sigfried (1992), which has been proven a useful tool for identifying the conservation priorities. In this method, the minimum number of required grid cells needed to capture all 14 *Pseudopodospermum* species was determined, the location of grid cells was mapped and their conservation priorities were also determined. The process is iterative, whereby the first cell is the richest in the number of species. The second iteration locates a grid cell that is richest in species not already represented in the first iteration, and this iterative process continues until all species be represented. Defining the grid cells as 50×50 km, we provided the "Sequences" and "Additional classes" grids on the map in which the nature reserves of Iran were designated. In addition, we calculated the area of the nature reserve overlapped with the existing sequences grid cells, using the intersect tool in ArcView ver. 3.2

RESULTS AND DISCUSSIONS

General overview

Following narrow circumscription of lineages within *Scorzonera* s.l. (Zaika & al. 2020, Hatami & al. 2022) that considered *Pseudopodospermum* at generic rank, we prepared an updated species checklist of this genus in Iran (Table 1). As mentioned in Zaika & al. (2020), *Pseudopodospermum* includes species previously placed in the *Scorzonera* subgenus *Pseudopodospermum* and also species from sections *Incisae*, *Foliosae*, *Papposae*, and *Hissaricae* of the former *Scorzonera* subgenus *Scorzonera*. All the species belonging to this genus possessed tuberous roots and entire leaves (except species of sect. *Incisae*), and tuberculate or verrucose appendages on achenes, which have been considered diagnostic morphological characters of this genus. Regarding Flora Iranica (Rechinger 1977), Flora of Iran (Safavi 2013), and all corresponding information obtained from relevant studies (Safavi 2019, Hatami & al. 2020, Zaika & al. 2020, Hatami & al. 2022), it was revealed that flora of Iran comprises 14 species.

Our results (Table 1) represented that the main distribution of *Pseudopodospermum* species (mentioned in our study) is in Iran, Turkey, Iraq, Afghanistan, and Pakistan. From the phytogeographical point of view (Table 1), it was confirmed that the Irano-Turanian region is the main distribution phytochorion for *Pseudopodospermum*,

consistent with previous studies representing that E Mediterranean and Irano-Turanian regions have been regarded as the main diversity centers of this genus (Zaika & al. 2022). However, further biogeographic studies are required to explore whether this genus originated in E Mediterranean or Irano-Turanian region. With regards to Irano-Turanian Provinces, it was revealed that most of the species are widespread in Kurdo-Zagrosian, Fars-Kerman and Atropatanean Provinces. Although, a group of species including *P. ovatum*, *P. picridioides*, *P. raddeanum*, and *P. tunicatum* is mainly found in N. Khorasan, Central Iran, and N. Baluchistan Provinces. In accordance with our field surveys, members of this genus are mostly distributed on the slopes of sandy-clay dunes or low-gradient slopes of mountains in humid to semi-arid areas. The presence of underground tubers in most species (probably except *P. calyculatum* and *P. incisum*) caused adaptation to ecological conditions such as low precipitation since the subterranean storage organ could provide the nutrition required at the beginning and also during the growing season (Dafni & al. 1981). These underground tubers would enable the plants to perennate in seasonal climates and persist through large fluctuations in climate from year to year (Raunkiaer 1934, Rees 1972).

Conservation status assessment of species in Iran

Based on the current information on the distribution pattern of each species, the conservation status of all *Pseudopodospermum* species in Iran was evaluated (Table 1). To categorize the threat status of taxa, we applied the four criteria of the IUCN (A-D; 2022), of which, the Extent of Occurrence (EOO) and Area of Occupancy (AOO) were obtained from GeoCAT analysis. The results represented that two species were assessed as Critically Endangered (CR), three species as Endangered (EN), four species as Vulnerable (VU), and five species as Near Threatened (NT). Therefore, it could be concluded that about %65 of all species have been classified into threatened categories (CR, EN, VU). Additionally, the rarity index (RI) was calculated for each species, ranging from 1 (*P. nivale*) to 0.025 (*P. picridioides* and *P. szowitzii*).

Pseudopodospermum nivale as an endemic species for the flora of Iran was only recorded from Kurdistan (Shahu Mountain) by Haussknecht in Flora Iranica (Rechinger 1977). *Pseudopodospermum limnophilum* is another rare species, having been reported only from two restricted areas in Fars and Lorestan Provinces (Rechinger 1977). Our field investigations for finding further specimens of these two taxa had no results. The conservation status of both taxa was assessed as Critically Endangered (CR, B1ab (iii); C2a(i); D), and they also possessed the highest rarity index (0.5-1). Thus, urgent conservation planning is required for both taxa, due to their restricted distributions and conservation status. In accordance with our results, the conservation status of *P. incisum*, *P. ovatum*, and *P. tunicatum*, was evaluated as Endangered (EN, B2ab(iii); C2a(i)). In total, the information on geographic occurrence, conservation status (EN), and rarity index (0.125-0.25) of these species confirmed a high priority on their conservation management. *Pseudopodospermum incisum* was recently reported as a new record for the flora of Iran (Safavi 2019). Six specimens of this species were collected from four populations in Kurdo-Zagrosian Province during our field surveys; however, this species is at high risk of extinction in Iran, because of its limited distribution and the wide range of threats it faces in Kurdo-Zagrosian Province. *Pseudopodospermum ovatum* is another species that was only recorded from Afghanistan and Turkmenistan (not from Iran) in Flora Iranica (Rechinger 1977); Safavi (2004) reported *P. ovatum* from the northeast of Iran, representing the first record of this species in the flora of Iran. Our field surveys confirmed the presence of this species in the east of central Iran, N. Baluchistan, and Fars-Kerman Provinces. Nevertheless, the *P. ovatum* is at risk, since the leaves of this species have been widely used as edible vegetables by local people in southeast Iran. To protect this species, improper harvesting of different populations of it in its habitats should be prohibited. Based on assembled data, the conservation status of *P. pappusum*, *P. raddeanum*, *P. syriacum*, and *P. turkeviczii* was assessed as Vulnerable (VU; B2, C2a(i); D1). Our field surveys revealed that a considerable decrease in the number of individuals of these species has occurred in their habitats. Therefore, their conservation is a high priority. The five remaining species including *P. calyculatum*, *P. mucidum*, *P. phaeopappum*, *P. picridioides*, and *P. szowitzii* possessed the lowest rarity index and were considered to be of Near Threatened (NT; B2b(iii)) conservation status. These species are in better conditions compared to the others, however, they may fall into a threatening situation in near future, because of some factors such as habitat destruction or livestock overgrazing. For instance, the *P. picridioides* may be at risk, because it has been widely used as vegetables in eastern regions of Iran, and overharvesting of the individuals has probably led to irreversible losses of this species in its habitats.

Species richness centers

The first two grid-based maps demonstrated the species richness (Fig. 1) and observations (Fig. 2) of *Pseudopodospermum* in Iran. According to our results, high species diversity was located in the western part of Iran, extending from northwest to southwest. Figure 1 represented that Fars and Kohgiluyeh va Boyer-Ahmad Provinces have the highest species richness. Based on the phytogeographical point of view, the hotspot of species richness occurred in the Kurdo-Zagrosian Province, followed by restricted areas in Fars-Kerman, Atropatanean, N. Khorasan, and Hyrcanian Provinces. The lowest number of species was found in the south, southeast, and central parts of Iran in N-Baluchistan, central Iran, and Nubo-Sindian Provinces.

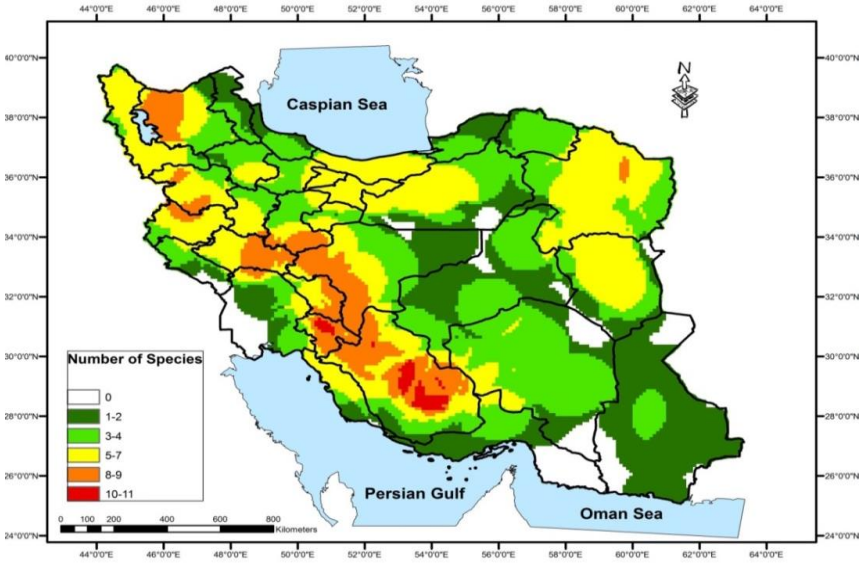

Fig. 1. Number of *Pseudopodospermum* species (richness) per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

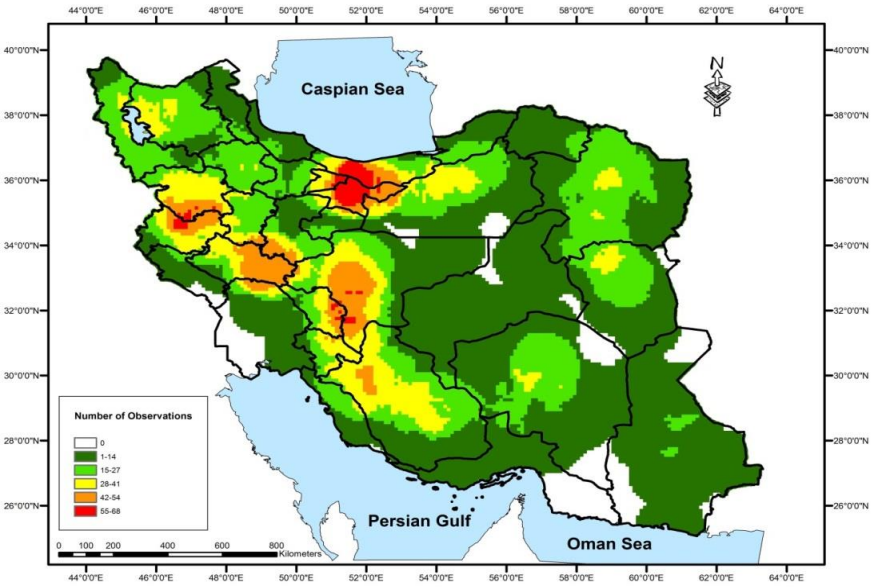

Fig. 2. Number of observations of *Pseudopodospermum* species per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

Table 1. Global distribution, Phytogeographical distribution in Iran (Based on Assadi's phytochoria, 2006): Rarity Index (RI); Extent of Occurrence (EOO); Area of Occupancy (AOO); Conservation status (CS) of representative Pseudopodospermum species. CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened; IT: Irano-Turanian, ES: Euro-Siberian, SS:Saharo-Sindian.

No	Species	Geographic distribution in the world	Phytogeographic distribution in Iran	RI	EOO [km^2]	AOO [km^2]	IUCN indexes	CS
1	*P. calyculatum* (Boiss.) Zaika, Sukhor. & N.Kilian	Iran, Iraq	IT(Kurdo-Zagrosian, Atropatanean) ES(Hyrcanian)	0.058	530,827.55	2725.00	B2b(iii)	NT
2	*P. incisum* (DC.) Zaika, Sukhor. & N.Kilian	Turkey, Iran	IT(Kurdo-Zagrosian)	0.25	22,194.19	175.00	B2ab(iii); C2a(i)	EN
3	*P. limnophilum* (Boiss.) E. Hatami, N. Kilian & K.E. Jones	Afghanistan, Iran	IT(Kurdo-Zagrosian)	0.5	0.00	8.00	B1ab(iii);C2a(i); D	CR
4	*P.mucidum* (Rech.f., Aellen &Esfand.), Zaika,Sukhor. & N.Kilian	Iran, Iraq	IT(Kurdo-Zagrosian, Fars-Kerman, N. Khorasan) ES(Hyrcanian), SS(Nubo-Sindian)	0.026	1,177,420.81	2575.00	B2b(iii)	NT
5	*P.nivale* (Boiss. & Hausskn.) E. Hatami,N. Kilian & K.E. Jones	Iran	IT(Kurdo-Zagrosian)	1	0.00	4.00	B1ab(iii);C2a(i); D	CR
6	*P.ovatum* (Trautv.) Zaika, Sukhor. & N.Kilian	Iran, Afghanistan, Kirgizistan, Tadzhikistan, Turkmenistan, Uzbekistan	IT(N. Baluchistan, Fars-Kerman, N. Khorasan)	0.25	360,709.24	150.00	B2ab(iii); C2a(i)	EN
7	*P. papposum* (DC.) Zaika, Sukhor. & N.Kilian	Iran, Iraq, Kuwait, Lebanon-Syria, Palestine, Saudi Arabia, Sinai, Armenia, Nakhichevan, Turkey	IT(Kurdo-Zagrosian, Atropatanean)	0.06	1,133,920.32	725.00	B2, C2a(i); D1	VU
8	*P. phaeopappum* (Boiss.) Zaika, Sukhor. & N.Kilian	Iran, Iraq, Lebanon-Syria, Palestine, Saudi Arabia, Turkey	IT(Kurdo-Zagrosian, Atropatanean) ES(Hyrcanian)	0.062	539,090.18	2450.00	B2b(iii)	NT
9	*P. picridioides* (Boiss.) Hatami	Iran, Afghanistan, Pakistan	IT(Central Iran, Fars-Kerman, N. Baluchistan, N. Khorasan) SS(Nubo-Sindian)	0.025	1,037,944.57	2600.00	B2b(iii)	NT
10	*P. raddeanum* (C.Winkl.) Zaika, Sukhor. & N.Kilian	Iran, Afghanistan, Tadzhikistan, Turkmenistan, Pakistan	IT(N. Khorassan, Fars-Kerman, Cental Iran)	0.027	1,083,619.73	1925.00	B2, C2a(i); D1	VU
11	*P. syriacum* (Boiss. & C.I.Blanche) Zaika, Sukhor. & N.Kilian	Iran, Iraq, Lebanon-Syria, Oman, Palestine, Saudi Arabia, Sinai, Turkey	IT(Atropatanean, Kurdo-Zagrosian)	0.055	697,429.73	825.00	B2, C2a(i); D1	VU
12	*P. szowitzii* (DC.) Kuth.	Iran, Transcaucasus (Abkhaziya, Adzhariya, Armenia, Azerbaijan, Georgia, Nakhichevan), Turkey	IT(Atropatanean, N. Khorasan, Kurdo-Zagrosian) ES(Hyrcanian)	0.025	1,072,298.85	2925.00	B2b(iii)	NT
13	*P. tunicatum* (Rech. f. & Köie) E. Hatami, N. Kilian & K.E. Jones	Iran, Afghanistan, Pakistan	IT(N. Khorasan, Central Iran)	0.125	118,245.09	400.00	B2ab(iii); C2a(i)	EN
14	*P. turkeviczii* (Krasch. & Lipsch.) Kuth.	Iran, Armenia, Iraq	IT(Kurdo-Zagrosian, Atropatanean)	0.076	202,101.76	650.00	B2, C2a(i); D1	VU

The mapping of the plant collections of all species (Fig. 2) showed that the highest number of observations were recorded in Mazandaran, Tehran, Esfahan, Chaharmahal va Bakhtiari, and Kermanshah Provinces, corresponding to some parts of the Hyrcanian and Kurdo-Zagrosian Provinces. Comparing the species richness and observation maps (Fig. 1 vs. Fig. 2) revealed an overlap of species range hotspots and areas of high observations in Kurdo-Zagrosian Province, thus, it has been considered the region with the highest species diversity and also the best-sampled area for this genus. The Kurdo-Zagrosian either defined as a province (Assadi 2006), district (Zohary 1973), or subprovince (Takhtajan 1986) contains the whole mountain system of the Zagros, extending from the Anatolian and Azerbaijan Plateau in the northwest to the Yazd-Kerman massif in the southeast (Noroozi & al. 2020). The Zagros Mountains are one of the most important centers of speciation in Iran, while, the huge area size of the Zagros and its diverse climate and topography have created a variety of ecosystems and habitats for many plant species with a high degree of endemism (Zohary 1973, Hedge & Wendelbo, 1978, Noroozi & al. 2020). As mentioned in previous studies, the flora of the Zagros possessed a relatively high number of geophytes (Noroozi & al. 2020). As an example, a remarkable diversity of East-Mediterranean orchids occurred in Zagros, compared to the relatively low number of orchid species in Iran (Renz 1978). Consistently, *Pseudopodospermum* taxa, classified as geophytes due to the presence of underground tubers (Raukiaer 1943), represented high species diversity in Zagros compared to other regions.

Furthermore, a comparison of richness and observation maps represented that Fars-Kerman, Atropatanean, and N. Khorasan Provinces were identified as relatively species-rich areas; however, these areas were not well explored. According to previous studies, these areas are among the important centers of diversity and endemism of many plant groups in Iran (Hatami & Khosravi 2013, Noroozi & al. 2018, Khajoei Nasab and Khosravi 2020, Mehrabian & al. 2020, 2021). Therefore, it is recommended to pay more attention to these areas; further explorations may lead to discovering additional species diversity. Our results also revealed that Hyrcanian Province possessed lower species diversity compared to Irano-Turanian region, whereas a considerable number of specimens were collected from this region (Fig. 1 vs. Fig. 2).

Conservation priorities and natural resources management

In general, identifying areas with high plant species richness and consequently defining biodiversity hotspots have provided valuable achievements that can be used in conservation strategies such as the conservation of endangered species and also selecting the habitat and geographic zone priorities (Meyers & al. 2000). It was also corroborated in previous studies (Kier & Barthlott 2001) that richness is the main criterion for prioritizing conservation, as the zones with the highest diversity have corresponded with the highest conservation priorities. Here, the "Additional classes" and "Sequences" grids, obtained from Complementary analysis in DIVA-GIS, have been proved useful for determining the areas with conservation priorities.

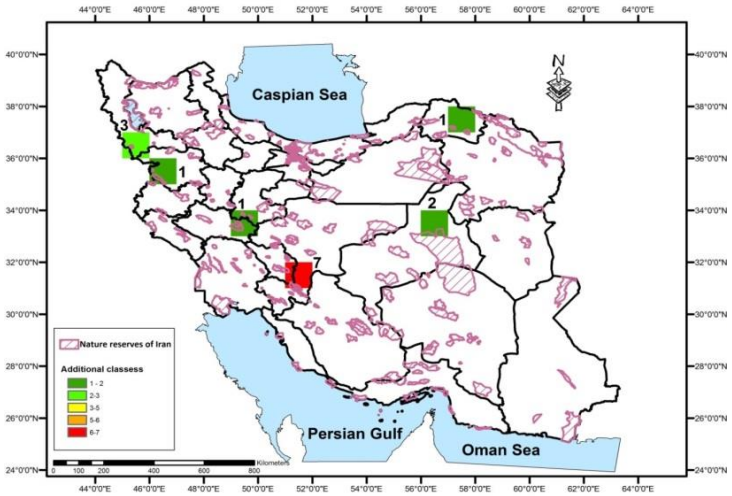

Fig. 3. The location of six 50×50 km grid cells needed to include all Pseudopodospermum species based on "Additional classes" grids in complementary analysis. The nature reserves of Iran are represented on the map.

Based on the additional classes map (Fig. 3), six grid cells are required to capture all *Pseudopodospermum* species. These grid cells are mainly located in Kurdo-Zagrosian, N. Khorasan, and Central Iran Provinces. The conservation priorities of those six grid cells were determined in the sequence map (Fig. 4). Comparing these two maps (Fig. 3 and Fig. 4) indicated that the priority rank of each grid cell coincided with the number of species contained therein. In our study, the grid cell with the biggest number of species was located in a region that covered small areas of Esfahan, Fars, and Chaharmahal va Bakhtiari Provinces. This grid cell was defined as the first priority for conservation. The second priority grid cell corresponding to the cell with three additional species was placed in the south of West Azerbaijan Province. In total, these two grid cells in Kurdo-Zagrosian Province are enough to cover almost %70 of all *Pseudopodospermum* species, thus, protecting these small areas would result in protecting the majority of species. Therefore, the significant species diversity as well as the occurrence of endemic and narrowly distributed species of this genus in Kurdo-Zagrosian, asks for a strong conservation policy. However, climate change, habitat destruction, and overgrazing are the main factors threatening the flora and vegetation types of this region. The grid cell with two additional species was placed in Central Iran Province (east of Yazd) and corresponded with the third conservation priority. The other three grid cells, each containing one species coincided with the fourth, fifth, and sixth priorities. The fourth priority grid cell was placed in N. Khorasan Province and the grid cells with the fifth and sixth priorities were located in Kurdo-Zagrosian Province, one was placed in Kurdistan and the other in Lorestan (Fig. 3 and 4). The significance of N. Khorasan and Central Iran Provinces for this genus could be related to the distribution pattern of some species such as *P. ovatum*, *P. picridioides*, *P. raddeanum*, and *P. tunicatum*, restricted to eastern and central parts of Iran, covering N. Khorasan, N. Baluchistan, and Central Iran Provinces, while they have not been found in western regions.

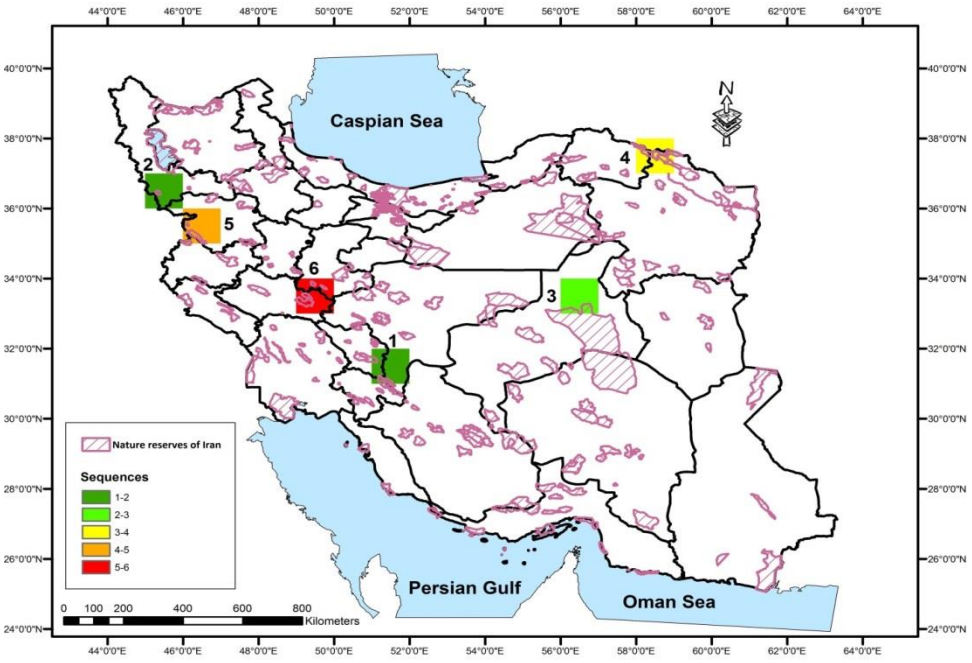

Fig. 4. The conservation priorities of six 50×50 km grid cells that included all Pseudopodospermum species based on grids " Sequences" in complementary analysis. The nature reserves of Iran are represented on the map.

In planning the conservation strategies for preserving the existing biodiversity over the wide geographic expanse of Iran, it has been confirmed that nature reserves have a fundamental role in conserving the local to regional biodiversity, particularly, the characteristic or threatened species, habitats, or ecosystems (Bali & Bahmanpoor 2012). The nature reserves of Iran, divided into four categories such as national parks, wildlife refuges, protected areas, and national natural monuments, are

under the management of the Iranian Department of Environment (Kolahi & al. 2013). While preparing the complementary analysis maps (Figs. 3 and 4), the nature reserves of Iran were implemented on both additional classes and sequences grid cells, so as to explore whether the six grids' cells designated for conservation priorities of *Pseudopodospermum* overlapped with the nature reserves. As inferred from figures 3 and 4, some nature reserves in Kurdo-Zagrosian, Central Iran, and N. Khorasan Provinces are overlapped with the additional classes and sequences grid cells. Our numerical analysis on calculating the coverage of sequences grid cells with the nature reserves revealed that approximately 6010 km^2 of the nature reserve areas (3.2% of the total area of nature reserves in Iran) overlapped with the six sequences grid cells. Hereupon, the presence of *Pseudopodospermum* species in only 3.2% of all nature reserves would intensify the necessity of conservation management of this genus in Iran. The grid cell with the highest number of species and also first conservation priority overlapped with the eastern part of Sabz Kuh Protected area, and north of Dena Protected Area as well as Dena National Park in Kurdo-Zagrosian Province. The next grid cell with the second priority which was located in the south of West Azarbaijan Province covered the Mirabad Protected Area. Moreover, the grid cells representing the fifth and sixth conservation priorities also overlapped with some nature reserves in Kurdo-Zagrosian Province. Therefore, well-designed management of the nature reserves in Kurdo-Zagrosian Province would lead to protecting a high percentage of *Pseudopodospermum* species against the threat of extinction in Iran. Consequently, it is highly recommended to reduce the conservation gaps in the Zagros by increasing the protected areas, national parks, and wild refuges. Furthermore, the grid cells with the third and fourth conservation priorities which were located in N. Khorasan and east of Central Iran Provinces covered some nature reserves in these regions, thus, these areas are also needed to be considered for the protection of *Pseudopodospermum* species. Nevertheless, more attention should be directed to conservation management of the specimens out of legal nature reserves, since several threatening factors such as increasing usage of the tubers and fresh leaves in folk medicine and overgrazing may intensify the threat of extinction of these species. As a final point, it could be concluded that utilizing statistical geographical approaches such as species richness and complementary analysis, as we performed in our study, would be helpful in identifying the conservation priorities.

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REFERENCES

Akkol, E. K., Acıkara, Ö. B., Süntar, I., Ergene, B. & Çitoğlu, G. S. 2012: Ethnopharmacological evaluation of some *Scorzonera* species: In vivo anti-inflammatory and antinociceptive effects. -Journal of Ethnopharmacology 140(2): 261-270. https://doi.org/10.1016/j.jep.2012.01.015

Assadi, M., Maassoumi, A. A., Khatamsaz, M. & Mozaffarian, V. (eds), 1988–2018: Flora of Iran. vols. 1–147. Research Institute of Forests and Rangelands Publications, Tehran.

Assadi, M. 2006: Distribution patterns of the genus *Acantholimon* (Plumbaginaceae) in Iran. Iranian Journal of Botany 12 (2): 114-120.

Bali, A. & Bahmanpoor, A. 2012: The distribution map of Iranian Protected Areas. –Tehran: Department of Environment.

Barthlott, W., Lauer, W. & Placke, A. 1996: Global distribution of species diversity in vascular plants: towards a world map of phytodiversity. -Erdkunde 50 (41): 317–327.

Bachman, S., Moat, J., Hill, A. W., De La Torre, J., & Scott, B. 2011: Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool. -ZooKeys 150: 117–126.

Crisp, M. D., Laffan, S., Linder, H. P. & Monro, A. 2001: Endemism in the Australian flora. -Journal of Biogeography 28:183-198. https:// doi.org/10.1046/j.1365-2699.2001.00524.x.

Cressie, N. A. C. 1991: Statistics for Spatial Data. John Wiley and Sons, New York, USA.

Dafni, A., Cohen, D. & Noy-Mier, I. 1981: Life-cycle variation in geophytes. -Annals of the Missouri Botanical Garden 652-660.

Dobson, A. P., Bradshaw, A. D. & Baker, A. Á. 1997: Hopes for the future: restoration ecology and conservation biology. -Science 277(5325): 515-522.

Esri, 2000: ArcView Gis Ver. 3.2a. Environmental Systems Research Institute Inc., California.

Hatami, E. & Khosravi, A. R. 2013: Mapping of the geographic distribution of C3 and C4 species of

the family Chenopodiaceae in Iran. -Iranian Journal of Botany 19:263-276. http://dx.doi.org/10.22092/ijb.2013.4164

Hatami, E., Mirtadzadini, M., Bordbar, F. & Jones, K. E. 2020: Delimitation of Iranian species of *Scorzonera* subg. *Podospermum* and *S*. subg. *Pseudopodospermum* (Asteraceae, Cichorieae) based on morphological and molecular data. – Willdenowia 50(1):39-63. https://doi.org/10.3372/wi.50.50105.

Hatami, E. & Mirtadzadini, M. 2022: Notes on the identity of Scorzonera picridioides and Scorzonera paradoxa (Asteraceae). -Feddes Repertorium 133(2): 152-161. https://doi.org/10.1002/fedr.202100044.

Hatami, E., Jones, K. E., & Kilian, N. 2022: New insights into the relationships within subtribe Scorzonerinae (Cichorieae, Asteraceae) using hybrid capture phylogenomics (Hyb-Seq). -Frontiers in Plant Science https://doi.org/10.3389/fpls.2022.851716.

Hedge, I. C. & Wendelbo, P. 1978: Patterns of distribution and endemism in Iran. Notes from the Royal Botanic Garden Edinburgh. 36(2): 441-464.

Hijmans, R. J. & Spooner, D. M. 2001: Geographic distribution of wild potato species. -American Journal of Botany 88(11): 2101-2112. https://doi.org/10.2307/3558435.

IUCN Standards and Petitions Committee. 2022: Guidelines for Using the IUCN Red List Categories and Criteria. Version 15.1. Prepared by the Standards and Petitions Committee. Available from https://www.iucnredlist.org/documents/RedListGuidelines.pdf.(accessed July 2022).

Jalili, A. & Jamzad, Z. 1999: Red data book of Iran: a preliminary survey of endemic, rare and endangered plant species in Iran. Research Institute of Forests and Rangelands, Tehran.

Jetz, W., Rahbek, C. & Colwell, R. K. 2004: The coincidence of rarity and richness and the potential signature of history in centers of endemism. -Ecology Letters 7(12): 1180-1191. https://doi.org/10.1111/j.1461-0248.2004.00678.x.

Khajoei Nasab, F. & Khosavi, A. R. 2020: Identification of the areas of endemism (AOEs) of the genus *Acantholimon* (Plumbaginaceae) in Iran. -Plant Biosystems 154: 726-736. https://doi.org/10.1080/11263504.2019.1686078.

Kier, G. & Barthlott, W. 2001: Measuring and mapping endemism and species richness: a new methodological approach and its application on the flora of Africa. -Biodiversity and Conservation 10(9):1513-1529. https://doi.org/10.1023/A:1011812528849.

Kier, G., Mutke, J., Dinerstein, E., Ricketts, T. H., Küper, W., Kreft, H. & Barthlott, W. 2005: Global patterns of plant diversity and floristic knowledge. -Journal of Biogeography 32(7): 1107-1116. https://doi.org/10.1111/j.1365-2699.2005.01272.x.

Kilian, N., Hand, R. & Raab-Straube, E. von general ed. 2009b+: *Cichorieae* Systematics Portal. Published at http://cichorieae.e-taxonomy.net/portal/.

Kolahi, M., Sakai, T., Moriya, K, Makhdoum, M. F. & Koyama, L. 2013: Assessment of the effectiveness of protected areas management in Iran: a case study in Khojir National Park. -Environmental Management 52(2): 514-530. https://doi.org/10.1007/s00267-013-0061-5.

Lendzion, K., Gornowicz, A., Bielawski, K. & Bielawska, A. 2021: Phytochemical Composition and Biological Activities of *Scorzonera* Species. International Journal of Molecular Sciences 22 (10):5128. https://doi.org/10.3390/ijms2210518.

Lipschitz, S. J. 1935: Fragmenty k monografii roda *Scorzonera* / Fragmenta Monographiae Generis *Scorzonera* L. [1]. Transactions of the Rubber and Guttapercha Institute, Moscow 1: 1–164 [in Russian].

Lipschitz, S. J. 1964: *Scorzonera* L. Pp. 27 – 111 in: Bobrov EG, Tzvelev NN (ed.), Flora URSS XXIX. Izdatelstvo "Nauka", Moskva and Leningrad [in Russian].

Mehrabian, A., Khajoei Nasab, F. & Amini Rad, M. 2021: Distribution patterns and priorities for conservation of Iranian Endemic Monocots: determining the Areas of Endemism(AOEs). -Journal of Wildlife and Biodiversity 5(2): 69–87. https://doi.org/10.22120/jwb.2020.136616.1188.

Mehrabian, A. R., Khajoei Nasab, F., Fraser-Jenkins, C. R. & Tajik, F. 2020a: Distribution patterns and priorities for conservation of Iranian pteridophytes. -Fern gazette 21(4):141–160.

Meyers, N., Mittermeier, R. A., Mittermeier, C. G. & da Fonseca, G. A. B. 2000: Biodiversity hotspots for conservation priorities. -Nature 403: 853–858. https://doi.org/10.1038/35002501.

Mutke, J. & Barthlott, W. 2005: Patterns of vascular plant diversity at continental to global scales. -Biologiske skrifter 55(4): 521-531.

Noroozi, J., Moser, D. & Essl, F. 2016: Diversity, distribution, ecology and description rates of alpine endemic plant species from Iranian mountains. -Alpine botany 126(1): 1-9 https://doi.org/10.1007/s00035-015-0160-4.

Noroozi, J., Talebi, A., Doostmohammadi, M., Rumpf, S. B., Linder, H. P. & Schneeweiss, G. M. 2018: Hotspots within a global biodiversity hotspot - areas of endemism are associated with high mountain ranges. -Scientific Report 8: 10345 https://doi.org/10.1038/s41598-018-28504-9.

Noroozi, J., Talebi, A., Doostmohammadi, M. & Bagheri, A. 2020: The Zagros Mountain range. In Plant Biogeography and Vegetation of High Mountains of Central and South-West Asia (pp. 185-214). –Springer, Cham.

Prendergast, J. R., Quinn, R. M., Lawton, J. H., Eversham, B. C. & Gibbons, D. W. 1993: Rare species, the coincidence of diversity hotspots and conservation strategies. -Nature 365(6444): 335-337 https://doi.org/10.1038/365335a0.

Raunkiaer, C. 1934: The Life Forms of Plants and Statistical Plant Geography. Clarendon Press, Oxford. 631 p.

Rebelo, A. G. 1994: Iterative selection procedures: centers of endemism and optimal placement of reserves. -Strelitzia, 1: 231–257.

Rebelo, A. G. & Siegfried, W. R. 1992: Where should nature reserves be located in the Cape Floristic Region, South Africa? Models for the spatial configuration of a reserve network aimed at maximizing the protection of diversity. -Conservation Biology 6: 243–252. https://doi.org/10.1046/j.1523-1739.1992. 620243.x

Rechinger, K. H. 1951: Grundzüge der Pflanzenverbreitung im Iran. -Zoologisch-Botanischen Gesellschaft in Wien 92:181–18.

Rechinger, K. H. 1977: *Scorzonera*. – Pp. 16 – 79 in: Rechinger K. H. (ed.), Flora iranica 122. Graz: Akademische Druck- u. Verlagsanstalt.

Rees, A. R. 1972: The Growth of Bulbs. Academic Press, London and New York. 291 p.

Reid, W. V. 1998: Biodiversity hotspots. -Trends in Ecology and Evolution 13: 275-280. https://doi.org/10.1016/S0169-5347(98)01363-9.

Renz, J. 1978: Orchidaceae vol 126. Flora Iranica. Akademische Druck-und Verlagsanstalt, Gra.

Safavi, S. R. 2004: A new record and an interesting species of the genus *Scorzonera* L. from Iran. -Iranian Journal of Botany 10(2): 159-162.

Safavi, S. R. 2013: *Scorzonera*. – Pp. 353 – 442 in: Safavi SR, Naseh Y, Jafari E, Tavakoli Z, Heidarnia N, Tribe *Cichorieae*, *Asteraceae*, Flora of Iran. 77. Research Institute of Forest and Rangelands, Tehran [in Persian].

Safavi, S. R. 2016: A new species of *Scorzonera* (Asteraceae) from Natanz, Iran. –Iranian Journal of Botany 22: 1-5.

Safavi, S. R. 2019: *Scorzonera incisa* (Asteraceae), as a new record from NW Iran. -Nova Biologica Reperta, 6(3): 334-337. https://dx.doi.org/10.29252/nbr.6.3.334.

Takhtadzhian, A. L., Takhtadzhian, L. A., Takhtajan, A. & Crovello, T. J. 1986: Floristic regions of the world. –University of California press.

Thiers, B. 2022 [continuously updated]: *Index Herbariorum: A global directory of public herbaria and associated staff.* New York Botanical Garden's Virtual Herbarium. Available from: http://sweetgum.nybg.org/science/ih/ (accessed 10 January 2022).

Wagnetiz, G. 1986: *Centaurea* in South-West Asia: Patterns of distribution and diversity. -Proceedings of the Royal Society of Edinburgh. Sect. B. Biological Sciences B 89: 11-21.

Williams, P., Gibbons, D., Margules, C., Rebelo, A., Humphries, C. & Pressey, R. L. 1996: A comparison of richness hotspots, rarity hotspots and complementary areas for conserving diversity using British birds. -Conservation Biology 10: 155–174. https://doi.org/10.1046/j.1523-1739.1996.10010155.x.

Zaika, M. A., Kilian, N., Jones, K., Krinitsina, A. A., Nilova, M. V., Speranskaya, A. S. & Sukhorukov, A. P. 2020: *Scorzonera* sensu lato (Asteraceae, Cichorieae) – taxonomic reassessment in the light of new molecular phylogenetic and carpological analyses. -PhytoKeys 137:1-85 https://doi.org/10.3897/phytokeys.137.46544

Zohary, M. 1973: Geobotanical foundations of the Middle East. Vol. 1-2. Gustav Fischer Verlag Press, Stuttgart. 739 pp.