Diversity centers as well as conservation priorities of the genus *Onosma* L. (Boraginaceae) in Iran

F. Khajoei Nasab1, 2, A. R. Mehrabian1, 3*

1 Department of Plant Sciences and Biotechnology, Faculty of Life Sciences and Biotechnology, Shahid Beheshti University, Tehran, Iran
2 ORCID iD: https://orcid.org/0000-0002-2325-9555
3 E-mail: a_mehrabian@sbu.ac.ir; ORCID iD: https://orcid.org/0000-0001-6633-3092

*Corresponding author

Keywords: areas of endemism, Boraginaceae, conservation, important plant areas, species richness.

Summary. Conservation of biological diversity is one of the most important issues in conservation biology, so a wide range of quantitative spatial methods have been used to determine the biodiversity hotspots and the conservation priority areas. The main aims of the present study are determining the areas of endemism as well as the centers of diversity of the genus *Onosma* based on the GIE, IPAs, species richness, and AZE-like criteria approaches, to assess the status and priorities of conservation of the mentioned genus in Iran. Based on the findings of this research, centers of species richness, the main areas of endemism, top-ranked IPAs, and AZE-like criteria are situated in the Zagros ecosystems. The comparison of the four approaches used in this study shows that the IPAs and GIE techniques have succeeded in identifying the most important centers of diversity and endemicism of *Onosma* in Iran. Considering that this genus with a high percentage of endemic species is one of the most important genera of Iranian flora and only 46% of the IPAs and areas of endemism specified in the research are located in protected areas, identification and protection of the rest of these areas is one of the prevalent measures needed for conservation of *Onosma* species diversity in Iran.

Центры разнообразия и приоритеты сохранения рода *Onosma* L. (Boraginaceae) в Иране

Ф. Хаджойи Насаб, А. Р. Меграбиан

Университет Шахида Бехешти, г. Тегеран, Иран

Ключевые слова: видовое богатство, ключевые ботанические территории, области эндемизма, сохранение, Boraginaceae.

Аннотация. Сохранение биологического разнообразия является одним из наиболее важных вопросов охраны природы. В настоящее время для определения очагов биоразнообразия и ключевых природоохранных зон используется широкий спектр аналитических методов. Основные цели настоящего исследования – выявление очагов эндемизма и центров видового богатства рода *Onosma* в Иране посредством географической интерполяции эндемизма (Geographical Interpolation of Endemism, GIE) и определения ключевых ботанических территорий (Important Plant Areas, IPA), а также оценка состояния и выработка стратегии сохранения рода на территории страны с использованием критериев, разработанных Альянсом за нулевое вымирание (Alliance for Zero Extinction, AZE). Результаты исследования показали, что центры видового разнообразия и основные районы эндемизма рода *Onosma* в Иране расположены в пределах Загроса, что было выявлено главным образом методами географической интерполяции эндемизма и определения ключевых ботанических территорий. Учитывая, что изучаемый род, характеризующийся высоким процентом эндемичных видов, является одним

Поступило в редакцию 24.07.2021
Принято к публикации 31.05.2022
Submitted 24.07.2021
Accepted 31.05.2022
Introduction

Rapidly declining global biodiversity (Myer, 1980) has led to increased rates of permanent damage to natural ecosystems and has reinforced the need for biodiversity data banking (Mutke, Barthlott, 2005). Data banking is the most important step in the planning of conservation priorities (Lovett et al., 2000; Kier et al., 2009). Conserving biodiversity is one of the most important targets of conservation biology (McNeely et al., 1990). Regardless, experts often believe that protection is not possible only through the creation of protected areas or reserves based on classic methods (Wilcove, 1989), so a wide range of quantitative methods has been used to determine the conservation-priority biodiversity hotspots (Myers, 1990).

Species richness (alpha diversity) is one of the most widely used measures to evaluate biodiversity hotspots. In addition to species richness, identifying areas of endemism (AOEs) and endemic diversity are among the most important approaches in evaluating the value of areas for protection. Endemic plants are the natural heritage of nations and represent the phytogeographic position and evolutionary history of the flora of each geographic area. Areas of endemism (AOEs) as one of the main candidates for protection of natural plant diversity have been evaluated by diverse methods such as PAE (Morrone, 1994), AE (Szumik, Goloboff, 2004), and GIE (Oliveira et al., 2015). The Alliance for Zero Extinction (AZE) sites are including the Key Biodiversity Areas (KBAs) that have one or more species listed as Endangered (EN) or Critically Endangered (CR) in the IUCN Red List of Threatened Species. Using AZE-like criteria could be another effective approach in determining protected areas at the regional levels. Recently the identification and conservation of Important Plant Areas (IPAs) have been endorsed according to Target 5 of the Global Strategy for Plant Conservation (GSPC-CBD). IPAs are identified at a national or regional level basis of three consistent criteria: the presence of threatened species, botanical richness, and the presence of threatened habitats (Anderson, 2002).

Onosma L. is the third large genus of plants in the borage family, Boraginaceae, with nearly 240 species of the biennial to perennial herbs (Popov, 1950, 1974; Zemskova, Popova, 1991; Jian-Chang et al., 1995; Mehrabian et al., 2013; Cecchi et al., 2016; Mehrabian, Amini Rad, 2018; Mehrabian, Mozaffarian, 2018; Khajoei Nasab et al., 2020a) distributed in mountain steppe of the Irano-Turanian region of Asia along with the Mediterranean region, especially Iran and Turkey (Meusel et al., 1978; Mehrabian, 2015; Cecchi et al., 2016; Khajoei Nasab et al., 2020b; Mehrabian et al., 2022a, b). So far about 69 plant taxa of this genus have been reported in Iran, many of which are endemic to the flora of Iran (Mehrabian, Amini Rad, 2018; Khatamsaz, 2002; Attar et al., 2020). Despite the importance of this genus in the world, there are few geographical and ecological studies on Onosma in the world. Mehrabian (2015) assessed distribution patterns and diversity of Onosma in Iran. Recently, distribution patterns, diversity, and conservation priorities of Onosma in some sections of the northwestern geomorphologic unit and Central Alborz of Iran were investigated (Moradi Zeinab et al., 2019; Khajoei Nasab et al., 2020a, b).

Iran has an exceptional plant species richness in southwest Asia, but so far relatively few comparative studies have been conducted using the IPA, AZE, GIE approaches. Considering the importance of the genus Onosma, comprehensive ecological and geographical studies in the species and habitat are necessary to determine the important areas of the diversity of this genus in Iran. The main aims of the present study are to determine the areas of endemism and centres of diversity based on IPAs and AZE-like criteria, to assess the status and priorities of conservation of this genus in Iran.

Materials and Methods

Study Area, Distribution and Ecology of the genus Onosma

Iran as a known country in southwestern Asia located in the dry belt of Asia between 24°–40°N longitude and 44°–64°E latitude, with a total surface area of 1.6 million km² and a population of about 81.5 million in 2018. The average elevation of Iran is 1305 m a. s. l. and Damavand is the highest peak (5771 m). The country is mostly mountainous (55 %) and is surrounded by several high mountain ranges (Fig. 1). The Zagros mountain range is 1600 km long and is the longest mountain range in Iran. Iran’s climate is
very diverse due to the vast extension of latitude, the existence of high mountains with extreme climate changes over altitudinal gradients, and the position of Iran between the Arabian desert areas and the eastern Mediterranean regions (Roozitalab et al., 2018). The desert and semi-arid climates are dominant climates due to Iran being located in the Afro-Asian desert belt. The average annual precipitation and average annual temperature in different regions of Iran are highly variable. *Onosma* is distributed in the highland ecosystems of Iran, including the Kopet Dagh in the northeast, the southern slopes of the Alborz, the western and eastern slopes of the Zagros, the Central Iran mountains and part of the Makran Mountains (Mehrabian, 2015) (Fig. 1). The genus is completely absent in desert areas in central Iran, as well as in the coastal areas of Caspian Sea, Persian Gulf and Oman Sea. *Onosma* species are found in four types of habitats:

1 - **Woodland of Quercus or Pistacia-Amygdalus in the Zagros.** Species are found in this type of habitat at altitudes between 1500–3100 m. Annual rainfall is more than 300 mm. Mediterranean pluviseasonal-continental and Mediterranean xeric-continental bioclimates predominate in these habitats. Species often grow in alkaline and organic matter-rich soils. *O. marivanensis* Mozaff. et Mehrabian, *O. mozaffariani* Mehrabian, *O. sheidaii* Mehrabian, *O. platyphylla* Riedl, *O. bakhteganensis* Mozaff. et Mehrabian, *O. sarvestanica* Mozaff. et Mehrabian and *O. sanandajensis* Mehrabian et Mozaff. are found in these habitats.

2 - **Mountain shrub-steppe.** These habitats are often found in the mountain ecosystems of northwestern (West Azarbaijan and Ardabil provinces) and Central Iran (Fars, Kerman and Yazd provinces). The altitude in these habitats is between 2000–3500 m. Mediterranean xeric-continental, Mediterranean pluviseasonal-oceanic and Mediterranean pluviseasonal-continental bioclimates constitute the dominant bioclimatic units in these habitats. *Onosma* species are commonly found in alkaline soils with sandy-loamy or sandy-loamy-clay texture (Moradi et al., 2019). The most prominent species of these habitats are *O. subsericea* Freyn, *O. stenosiphon* Boiss., *O. sabalanica* Ponert. and *O. elwendica* Wettst.

3 - **Mountain shrub-meadow steppe.** These habitats harbor many species of this genus in the uplands of Alborz, Kopet Dagh, Zagros, and parts of Central Iran. Altitude in these habitats varies between 300–3100 m and often has a gentle-steep slope. Mediterranean pluviseasonal-continental, Mediterranean pluviseasonal-oceanic, Mediterranean xeric-continental, and Mediterranean desertic-continental bioclimates are

Fig. 1. Map of the study area and Occurrences points of *Onosma* spp. in Iran.
found in these habitats. Species such as *O. gaubae* Bornm., *O. longiloba* Bge., *O. mousavi* Mehrabian et Amini Rad, *O. pachypoda* Boiss., *O. rascheyana* Boiss. and *O. sericea* Willd grow in these habitats. A small number of species such as *O. straussii* Khatamsaz and *O. bulbotricha* DC. are found in this habitat.

### Methods

**Data banking**

We prepared a geo-referenced database of *Onosma* species from all sites of this genus reported in Iran. The main distribution data sources include historical data available in “Flora Iranica” (Riedl, 1967), “Flora of Iran” (Khatamsaz, 2002), information provided by recently published articles (Ranjbar, Almasi, 2015; Mehrabian et al., 2013, 2018a), and recent data obtained from our fieldworks during 2009–2018 (acronyms according to Thiers, 2019). In this study, more than 400 surveys were conducted in 300 areas across 27 provinces of Iran. The “Flora Iranica” as well some new Iranian literature (e.g. Mehrabian et al., 2013; Mehrabian, Amini Rad, 2018; Mehrabian, Mozaffarian, 2018) and the website of Tropicos (www.Tropicos.org) and IPNI (www.IPNI.org) were used to determine nomenclature and species description information.

**IPAs and AZE sites**

In biological conservation studies, the grid-based ranking system has been widely used to determine the patterns of biodiversity (McAllister et al., 1994), hotspots of species richness (Lawton et al., 1994), areas of endemism and recently in the identification of the important plant areas (Al-Abbasí et al., 2010; Dagher-Kharrat et al., 2018). The important plant areas (IPAs), total species richness, and endemic species richness of the genus *Onosma* were mapped in 0.25° × 0.25° resolution Universal Transverse Mercator (UTM) grid cells using Geographic Information System (ArcView vs.10.3). We applied the methodology available in Plantlife International guidelines (Anderson, 2002) and other methodologies used in the recent studies (Marignani et al., 2014; Dagher-Kharrat et al., 2018) to identify IPAs worldwide. Plantlife has established three criteria to qualify IPAs following Criterion A (threatened species), Criterion B (botanical richness), and Criterion C (threatened habitats). We used the scoring method to determine the rank of each grid using the three calculated criteria (A, B, C), combined all scores for each grid cell and ranked them. One of the measured indices used here is botanical richness (criterion B) which refers to the number of plant species present in each grid cell which is useful for measuring taxonomic diversity (Gaston, 1996). The richness index was obtained by calculating the species richness of each grid cell and ranking the cells into five levels from 0 to 5 using the Jenks natural breaks classification method (Supplementary). The presence of threatened species in each cell (specific index (SP_index)) was also calculated (Supplementary). The list of species that satisfy criterion A or SP_index was based on three arbitrary scales: I. IUCN red list of species. II. Rarity. III. Endemism. The red list of species was assessed based on IUCN criteria at the regional scale (IUCN, 2011) calculated by Kew GeoCAT (http://geocat.kew.org; Buchman et al., 2011) and species were assigned to one of the following categories: Least Concern (LC), Data Deficient (DD), Near Threatened (NT), Vulnerable (VU), Endangered (EN) and Critically Endangered (CR) (Supplementary). Then a different score was given to each red-list category according to their importance i.e. 0 = Least Concern (LC), 1 = Vulnerable (VU), 2 = Endangered (EN) and 3 = Critically Endangered (CR). Species rarity was calculated using the index of species rarity (RI) (Supplementary). The RI was computed as the inverse of the cell numbers, including the target area, as RI = 1/Ci, where Ci is the number of grid cells and l is the number of taxa present (Selvi, 1997; Sapir et al., 2003) (Supplementary). The three categories and scoring based on this index were: very rare = 2, rare = 1, not rare= 0. Endemism levels for any species were as follows: endemic of three, two, and one phytogeographical provinces in Iran were scored 3, 2, and 1, respectively, and non-endemic species were scored 0 (Supplementary). The threatened habitats or habitat index (HAB_index) was based on the uniqueness and severity and the importance of each habitat during our fieldwork. Woodland of *Quercus* or *Pistacia – Amygdalus* were scored 4, Mountain shrub-steppe were scored 3, Mountain shrubs-meadow steppe was scored 2, Mountain meadow steppe was scored 1, Wasteland and agricultural habitat were scored 0. Finally, the IPA index was obtained from the sum of the points of these three indices (Supplementary). We identified AZE sites using three criteria Irreplaceability, Discreteness, and Endangerment (Langhammer, 2007). AZE sites were mapped using the number of endangered and critically endangered species in each grid cell 0.25° × 0.25° using Diva-GIS software.
Areas of Endemism (AOEs)

Most of the methods used to identify areas of endemism like PAE (Morrone, 1994) and AE (Szumik, Goloboff, 2004) use grid cells as spatial units that the size of these cells which can affect the results. Also, when a species occurs at the edges of the cells, assigning this species to a cell can also change the results. Using neighboring grid cells grouping techniques can solve the problems associated with using grid-based methods. We applied the Geographical Interpolation of Endemism (GIE) method to delimit areas of endemism of Onosma in Iran. This method was first proposed by Oliveira et al. in 2015. The GIE includes neighboring grid cells methods and identifies the areas of endemism by estimating the overlap between the distribution of species through a kernel interpolation of centroids of species distributions (Oliveira et al., 2015). Areas of endemism were identified using the GIE method in the ArcGIS software ver.10.3.

Results

In total, our database of Onosma populations contained of 1625 entries recording the presence of this genus in different parts of Iran (Fig. 1). The species richness map shows that mountainous regions of Iran such as Alborz, Zagros, Kopet Dagh, and the mountain range of the central and southern Iran are among the most desirable habitats of this genus (Fig. 2). According to our analysis the probability of the presence of this genus in the lowland and desert areas such as the central parts of Iran and the northern and southern coastal strip is zero, and so far no species has been reported in these areas. We categorized the species richness map cells into five groups of 1 to 12 species. The highest species richness (12 species) of this genus occurred in one grid cell in the parts of the Central Zagros, namely, Dalahu County in Kermanshah province (Fig. 2). Also, two grid cells have 8 to 10 species: a cell located in Doruod of Lorestan
province and the other located at the border between Tehran and Karaj. In addition, 19 grid cells have 6–7 species, often concentrated in the northern, western, northwest, and south-western parts of Iran. The Alborz and Zagros mountains in the north, northwest, and parts of southern Iran contain 91 grid cells with 3–5 *Onosma* species. The map of endemic species richness was categorized into four groups of 1 to 4 species (Fig. 3). The highest endemic species richness occurs in two cells (4 species) in Lorestan province and followed by 4 grids in Lorestan province, two cells in Kermanshah province, two cells in Central Alborz, and two cells in Fars province each with three endemic species. There are also 22 cells in Zagros ecosystems, 3 cells in central Alborz, one cell in Azerbaijan, and 2 cells in southeastern Iran, each of which has two *Onosma* endemic species.

![Endemic Species Richness map of the genus Onosma in Iran.](image)

**IPAs and AZE sites**

Based on the findings of this research, the IPA index values ranged between 2 to 28, which was classified into five groups ranging from very high to low values using the Jenks natural breaks classification method (Fig. 4). According to this method, 12 grid cells are in class 5 (very high value), 23 cells into the class 4 (high value), 32 grids into the class 3 (important value), 89 cells in class 2 (medium value), and the remaining cells into the class 1 (low value).

Information about the top-ranking cells are listed in Table, and this table shows that 67 % of the grid cells (8 cells) with very high IPA value are located in the Zagros Mountains and Kermanshah province has the largest number of grid cells of class 5. Parts of the Central Alborz, i.e. Tehran and Alborz provinces, include 0.25 % (3 grid cells) of the very high value of the IPA index as well as a small part of northwest Iran located between the Alborz and the Caucasus Mountains in Ardebil province. We identi-
Areas of Endemism (AOEs)

The GIE method was identified four main areas of endemism for this genus in Iran (Fig. 7). The two major areas of endemism of the genus *Onosma* are situated in the Zagros Mountain, i.e. AOE1 and AOE2. These regions have the highest Kernel index, and then the two areas in the Central Alborz (AOE3) and Ardabil-West Azarbaijan provinces (AOE4) have the highest rates of this index. AOE1 is located in the middle parts of the Central Zagros. The area covers the major parts of Lorestan, Hamedan and Markazi provinces. AOE1 is influenced by seven endemic species: *O. asperrima*, *O. kotschyi*, *O. platyphylla*, *O. bilabiata* Boiss., *O. straussii*, *O. chrysochaeta* Bornm. and *O. kilouyense* Boiss. et Hausskn. are found in this area. Moving northwest, the next AOE identify in Kermanshah and Kurdistan provinces. AOE2 is the richest area of endemism, which harbors 10 species of all Iranian *Onosma* endemics. All species in AOE1 present in this area except *O. asperrima* and *O. chrysochaeta*. In addition, there are five local endemic species named *O. iranshahrrii* Ghahreman et Attar, *O. bisotunensis* Attar et Hamzehée, *O. sheidaii*, *O. sanandajensis* and *O. marivanensis* in this area. AOE3 occupies most of the Central Alborz region. This area is located in the provinces of Alborz, Tehran and Mazandaran. AOE3 is influenced by four endemic species, i.e. *O. pachypoda*, *O. gaubae*, *O. chrysochaeta* and *O. kilouyense*. In this area, there are two endemic species of Alborz, namely *O. pachypoda* and *O. gaubae*. The northernmost area, named AOE4, is located in the provinces of Ardabil and West Azarbaijan. This area is defined by influence from four endemic species: *O. chrysochaeta*, *O. ilabiate*, *O. sabalanica*, and *O. assadi*.

Discussion

The results of the present study show that high species richness, the main areas of endemism, top-ranked IPAs, and AZE sites of this taxon are situated in the Zagros ecosystems. The Zagros mountains have been identified as important centres of species richness and areas of endemism for many important plant species in Iran (Hedge, Wendflo, 1978), including some alpine plant species and subgroups of true subnival and nival plants in Iran (Noroozi et al., 2008, 2011), endemic trees and shrubs (Mehrabian et al., 2020) and the genus *Acantholimon* (Khajoei Nasab, Khosravi, 2020). Special topographic heterogeneity, high annual rainfall, dominant Mediterranean

| Grid Number | IPA INDEX | SP_RICHNESS | Richness INDEX | Sp-INDEX | Hab INDEX | Province |
|-------------|-----------|-------------|----------------|----------|----------|----------|
| 1           | 28        | 11          | 5              | 16       | 7        | Kermanshah |
| 2           | 26        | 3           | 2              | 17       | 7        | Kermanshah |
| 3           | 26        | 4           | 2              | 17       | 7        | Kurdistan |
| 4           | 23        | 7           | 3              | 15       | 5        | Kermanshah |
| 5           | 20        | 6           | 3              | 11       | 6        | Kurdistan |
| 6           | 19        | 4           | 2              | 14       | 3        | Tehran     |
| 7           | 18        | 9           | 4              | 11       | 3        | Alborz-Tehran |
| 8           | 18        | 7           | 3              | 8        | 7        | Kurdistan |
| 9           | 16        | 6           | 3              | 10       | 3        | Alborz     |
| 10          | 16        | 9           | 4              | 8        | 4        | Lorestan   |
| 11          | 15        | 3           | 2              | 8        | 5        | East Azarbaijan |
| 12          | 15        | 5           | 2              | 9        | 4        | Lorestan   |
pluviseasonal-continental (Djmalí et al., 2011) in Zagros have led to high plant diversity and the creation of various habitats including oak forests, shrubs and grasslands and other types of habitats. The existence of these diverse habitats across the high mountain range has led to an increase in species richness and the number of local endemic species of this genus such as *O. mozaffariani* Mehrabian and *O. sheidaii* Mehrabian. In addition, three top-ranked IPAs and one area of endemism are located in the central Alborz region. The Central Alborz ecosystems, including important centers of speciation and endemism in Iran (Hedge, Wendelbo, 1978). This pattern corresponds well with the Alborz distribution pattern of endemism of montane/Alpine area of Irano-Turanian region (Hedge, Wendelbo, 1978; Noroozi et al., 2008, 2011, 2018; Khajoei Nasab, Khosravi, 2020). As well as one IPA and area of endemism have been identified in Ardebil province. Northwest Iran is an important center of speciation of plants in the country which is considered as the Atropatanene province of Irano-Turanian region. This area is located in the intersection of the Alborz, the Zagros and the Caucasus mountain ranges. In addition, mentioned area covers two different bioclimatic zones following Mediterranean xeric-continental (Mxc) and Mediterranean pluviseasonal-oceanic (Mpo) (Djmalí et al., 2011), so mentioned conditions created special habitats for various of the endemic species of *Onosma* such as *O. sabalanica* Ponet, as well as the Asteraceae family (Noroozi et al., 2018). The comparison of the four approaches used in this study (IPAs, AZE sites, GIE, and Species Richness) shows that the IPAs and GIE techniques have succeeded in identifying the most important centres of diversity and endemism of *Onosma* in Iran. The highest species rich-
Fig. 5. AZE map of the genus *Onosma* in Iran.

Fig. 6. Comparison of the map of protected areas of Iran and IPAs, AZE.
ness is associated with the highest IPAs index that occurred in Dalahu county. However, in a number of top-ranked IPAs, IPAs index does not show correlation with species richness (see IPAs and richness maps) due to the presence of grid with the high species index or presence of important habitats in some cells with lower species richness. Also by examining IPAs, AZE sites, total species richness and endemic species richness maps reveal that endemic species or endangered and critically endangered species don’t necessarily exist where the total number of species is greater, so it is natural that the high IPAs index is not associated with the high richness index in some cells. Some studies in this field have the same result. For example, a study done on bryophyte diversity in the Peneda-Gerês National Park (Portugal) indicated that high species richness associated with high IPAs index, but this does not apply to all grid cells (Sérgio et al., 2012). Species richness is a key criterion in biogeographical studies and conservation strategies but alone is not enough to provide a comprehensive assessment of plant diversity.

**Conclusion**

According to the findings of this research, we suggest that all the areas marked with these four approaches should be protected. We consider that this genus with a high percentage of endemic species is one of the most important genera of Iranian flora and only 46% of the IPAs and areas of endemism specified in the research are located in protected
areas, therefore, identification and protection of these areas are one of the most prevalent conservation planning. Finally, we suggest that plant protection research can not only be based on one approach and a new combination of quantitative methods should be used for conservation planning in the flora of Iran.

Acknowledgements

We are grateful to A. Nemati, S. Naghizadeh, M. J. Nikjouyan, and H. Moradi for their help in conducting field studies.

REFERENCES / ЛИТЕРАТУРА

Al-Abbasi T. M., Al-Farhan A., Al-Kuhlaidi A.W., Hall M., Llewellyn O. A., Miller A. G., Patzelt A. 2010. Important Plant Areas in the Arabian Peninsula. Edinb. J. Bot. 67(1): 25–35. DOI: 10.1017/S0960428609990217

Almasi M., Ranjbar, M. 2015. Onosma maculata sp. nov. (Boraginaceae) from Iran. Nord. J. Bot. 33: 522–525. DOI: 10.1111/njbo.00614

Anderson S. 2002. Identifying Important Plant Areas: a site selection manual for Europe. In: Plantlife. URL: https://www.plantlife.org.uk/uk/our-work/publications/identifying-important-plant-areas-site-selection-manual-europe.

Attar F., Sotoodeh A., Mirtazadzadini M. 2020. Four new species in subsection Asterotricha for the genus Onosma L. (Boraginaceae) from flora of Iran. Feddes Repert. 131: 146–158. DOI: 10.1002/fedr.202000005

Barthlott W., Hostert A., Kier G., Küper W., Kreft H., Mutke J., Rafiqpoor M. D., Sommer J. H. 2007. Geographic patterns of vascular plant diversity at continental to global scales. Erdkunde 61: 305–315. DOI: 10.3111/erdkunde.2007.04.01

Buchan A. S., Leurgans S. E., Boyle P. A., Schneide R. J. A., Arnold S. E., Bennett D. A. 2011. Combinations of motor measures more strongly predict adverse health outcomes in old age: The rush memory and aging project, a community-based cohort study. BMC Medicine 9: 42.

Cecchi L., Coppi A., Selvi F. 2016. Onosma juliae (Boraginaceae), a new species from southern Turkey, with remarks on the systematics of Onosma in the Irano-Turanian region. Phytotaxa 288: 201–213. DOI: 10.11646/phytotaxa.288.3.1.

Dagher-Kharrat M. B., El Zein H., Rouhan G. 2018. Setting conservation priorities for Lebanese flora – identification of important plant areas. J. Nat. Conserv. 43: 85–94. DOI: 10.1016/j.jnc.2017.11.004

Djamali M., Akhani H., Khoshravesh R., Andrieu-Ponel V., Ponel P., Brewer S. 2011. Application of the Global Bioclimatic Classification to Iran: implications for understanding the modern vegetation and biogeography. Ecol. Mediterr. 37: 91–114.

Gaston K. J. 1996. Species richness: measure and measurement. In: K. J. Gaston (ed.). Biodiversity: biology of numbers and difference. Oxford: Blackwell Science. Pp. 77–113.

Hedge I.C., Wendelbo P. 1978. Patterns of distribution and endemism in Iran. Notes Roy. Bot. Gard. Edinb. 36: 441–464.

Jian-Chang N., Yi-Zhen X., Yu-Long Z. 1995. A comparative palynological study on the Maharanga and Onosma (Boraginaceae). Acta Phytotaxonomica Sinica 33(1): 52–57.

Khatsamzas M. 2002. Boraginaceae. In: M. Assadi, A. A. Maassoumi, M. Khatamsaz (eds.). Flora of Iran. Tehran: Research Institute of Forests and Rangelands. Pp. 114–167.

Khajoei Nasab F., Khosavi A. R. 2020. Identification of the areas of endemism (AOEs) of the genus Acantholimon (Plumbaginaceae) in Iran. Plant Biosyst. 154: 726–736. DOI: 10.1002/plbo.202000005

Khajoei Nasab F., Mehrabian A. R., Nemati A. 2020a. Taxonomic revision of the genus Onosma gauvae sensu lato (Boraginaceae) based on morphological and ecological analysis. Plant Biosyst. 155: 1019–1031. DOI: 10.1080/11263504.2020.1813827

Khajoei Nasab F., Mehrabian A.R., Mostafavi H. 2020b. Mapping the current and future distributions of Onosma species endemic to Iran. J. Ariad Land 12: 1031–1045. DOI: 10.1007/s40333-020-0080-z.

Kier G., Kreft H., Lee T. M., Jetz W., Ihisch P. L., Nowicki C., Mutke J., Barthlott W. 2009. A global assessment of endemism and species richness across island and mainland regions. Proc. Natl. Acad. Sci. U.S.A 106: 9322-7. DOI: 10.1073/pnas.0810306106

Langhammer P. F., Bakarr M. I., Bennun L., Brooks T. M., et al. 2007. Identification and gap analysis of key biodiversity areas: targets for comprehensive protected area systems. Gland, Switzerland: IUCN. Ser. 15. xiv. 116 pp. DOI: 10.2305/IUCN.CH.2006.PAG.15.en

Lawton J. H., Prendergast J. R., Eversham B. C. 1994. The numbers and spatial distribution of species: analyses of British data. In: P. L. Forey, C. J. Humphries, R. I. Vane-Wright (eds.). Systematics and Conservation Evaluation. Oxford: Clarendon Press. Pp. 177–195.

Lovett J. R., Rudd S., Taplin J., Frimodt-Moller C. 2000. Patterns of plant diversity in Africa south of the Sahara and their implications for conservation management. Biodivers. Conserv. 9: 37–46. DOI: 10.1023/A:1008956529695
Mehrabian A. R. 2015. Distribution patterns and diversity of Onosma in Iran: with emphasis on endemism conservation and distribution pattern in SW Asia. Rostanlha 16: 36–60. DOI: 10.22092/BOTANY.2015.101996

Mehrabian A, Amini Rad M. 2018. Onosma moussavi sp. nov. (Boraginaceae) from Zagros Mountain (s), Iran. Feddes Repert. 29: 304–311. DOI: 10.1002/fedr.201700020

Mehrabian A., Mozaffarian V. 2018. Seven New Species of Onosma L. (Boraginaceae) with emphasis on their habitats in Iran. Taiwania 4: 366–388. DOI: 10.6165/tai.2018.63.366.

Mehradi Zeinab H., Mehrabian A. R., Mozaffarian V., Noroozi J. 2012. Bryophyte diversity in the Peneda-Gerês National Park (Portugal): selecting Important Plant Areas (IPA) based on a new survey and past records. Biologiske Skrifter 16: 395–408. DOI: 10.1007/s10531-011-0029-9

Meusel H., Jüger E., Rauschert S., Weinert E. 1978. Vergleichende Chorologie der zentraleuropäischen Flora-Karten-Band II. Jena: Gustav Fischer Verlag. 421 pp.

Moradi Zeinab H., Mehrabian A. R., Naghizadeh S., Mostafavi H., Khajoei Nasab F. 2019. Distribution patterns, diversity and conservation priorities of Onosma L. (Boraginaceae Juss.) in some sections of the northwestern geomorphologic unit of Iran. Environmental Sciences 17: 73–94.

Morrone J. J. 1994. On the identification of areas of endemism. Syst. Biol. 43: 438–441. DOI: 10.1093/sysbio/433438

Mutter J., Barthlott W. 2005. Patterns of vascular plant diversity at continental to global scales. Biologiske Skrifter 55: 521–537.

Myers N. 1990. The biodiversity challenge: expanded hotspots analysis. The Environmentalist 10: 243–256. DOI: 10.1007/BF02239720

Noroozi J., Akhani H., Breckle S-W. 2008. Biodiversity and phytogeography of the Alpine flora of Iran. Biodivers. Conserv. 17: 493–521. DOI: 10.1007/s10531-976-9246-7

Noroozi J. Pauli H., Grabherr G., Breckle S-W. 2011. The subnival-nival vascular plant species of Iran: a unique high-mountain flora and its threat from climate warming. Biodivers. Conserv. 20: 1319–1338. DOI: 10.1007/s10531-011-0029-9

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. Sci. Rep. 8: 10345. DOI: 101038/s41598-018-28504-9

Oliveira U., Brescovit A. D., Santos A. J. 2015. Delimiting Areas of Endemism through Kernel Interpolation. PLoS ONE 10(1): e0116673. DOI: 101371/journal.pone0116673

Popov M. G. 1950. O primenenii botaniko-geograficheskogo metoda v sistematie raseniy. Problemy botaniki I: 70–108. [In Russian] (Попов М. Г. О применении ботанико-географического метода в систематике растений // Проблемы ботаники, 1950. Т. 1. С. 70–108).

Popov M. G. 1974. Onosma L. In: Б. К. Шишкин (ed.). Flora of the U.S.S.R. Vol. 19. Tubiflorae. Jerusalem: Keter Publishing House. Pp. 136–171.

Riedl H. 1967. Boraginaceae. In: K. H. Rechinger (ed.). Flora Iranica 48. Graz: Akademische Druck-u Verlagsanstalt. Pp. 169–212.

Rooztalab M. H., Siadat H., Farshad A. 2018. The Soils of Iran. Switzerland: Springer. 255 pp.

Sapir Y., Shmida A., Fragman O. 2003. Constructing red numbers for setting conservation priorities of endangered plant species: Israeli flora as a test case. J. Nat. Conserv. 11: 91–107. DOI: 101078/ 1617-1381-00041

Selvi F. 1997. Rare plants on mount Aiata, Italy: vulnerability to extinction on an ecological "Island". Biol. Cons. 81: 257–266. DOI: 10.1016/S0006-3207(96)00155-3

Sérgio C., García C.A., Hespanhol H., Vieira C., Stow S., Long D. 2012. Bryophyte diversity in the Peneda-Gerês National Park (Portugal): selecting Important Plant Areas (IPA) based on a new survey and past records. Botánica Complutensis 36: 39–50.

Szumik C., Goloboff P. A. 2004. Areas of endemism: an improved optimality criterion. Syst. Biol. 53: 968–977. DOI: 101080/10635150490888859
Thiers B. 2019. *Index herbariorum: A global directory of public herbaria and associated staff*. New York Botanical Garden’s Virtual Herbarium. URL: http://sweetgum.nybg.org/ih (Accessed 15 January 2022).

Wilcove D. S. 1989. Protecting biodiversity in multiple-use lands: lessons from the US Forest Service. *Trends Ecol. Evol.* 4: 385–388. DOI: 10.1016/0169-5347(89)90108-0

Zemskova E. A., Popova T. N. 1991. The palynomorphological investigation of the genus *Onosma* (Boraginaceae). *Bot. Zhurn.* 76(9): 1279–1291. [In Russian] (Земскова Е. А., Попова Т. Н. Палиноморфологическое исследование рода *Onosma* (Boraginaceae) // Бот. журн., 1991. Т. 76, № 9. С. 1279–1291).

**Supplementary**

The list of species that satisfy criterion A or SP_index was based on three arbitrary scale: I. IUCN red list of species. II. Rarity. III. Endemism.

| Species                  | IUCN score | Rarity score | Endemism score | Endemism chorology | The extent of occurrence (EOO) | RI |
|--------------------------|------------|--------------|----------------|--------------------|--------------------------------|----|
| *Onosma albo-rosea* Fisch. et C. A. Mey. | 0 | 0 | 0 | 0 | LC | 0.1 |
| *Onosma ambigens* Lacaita | 1 | 2 | 0 | 0 | VU | 0.5 |
| *Onosma armena* DC. | 0 | 0 | 0 | 0 | LC | 0.09 |
| *Onosma asperrima* Bornm. | 0 | 0 | 1 | 3 | LC | 0.07 |
| *Onosma assadi* Mehrabian et Mozaff. | 2 | 2 | 3 | 1 | EN | 0.5 |
| *Onosma azarbaidjanensis* Mehrabian. | 2 | 2 | 3 | 1 | EN | 1 |
| *Onosma bakhteganensis* Mozaff. et Mehrabian | 2 | 2 | 3 | 1 | EN | 0.5 |
| *Onosma bilabiata* Boiss. | 0 | 1 | 2 | 2 | LC | 0.14 |
| *Onosma bisotunensis* Attar et Hamzehee | 2 | 2 | 3 | 1 | EN | 0.5 |
| *Onosma bodeana* Boiss. | 0 | 0 | 0 | 0 | LC | 0.08 |
| *Onosma bulbotricha* DC. | 0 | 0 | 0 | 0 | LC | 0.03 |
| *Onosma caerulescens* Boiss. | 1 | 2 | 0 | 0 | VU | 0.5 |
| *Onosma cardiostegia* Bornm. | 0 | 1 | 0 | 0 | LC | 0.12 |
| *Onosma chlorotricha* Boiss. | 0 | 0 | 0 | 0 | LC | 0.07 |
| *Onosma chrysochaeta* Bornm. | 1 | 1 | 2 | 2 | VU | 0.33 |
| *Onosma cornuta* H. Riedl. | 0 | 0 | 0 | 0 | LC | 0.07 |
| *Onosma dasytricha* Boiss. | 0 | 0 | 0 | 0 | LC | 0.05 |
| *Onosma demawendica* Riedl | 1 | 1 | 3 | 1 | VU | 0.25 |
| *Onosma dichroantha* Boiss. | 0 | 0 | 0 | 0 | LC | 0.04 |
| *Onosma elwendica* Wettst. | 0 | 0 | 0 | 0 | LC | 0.03 |
| *Onosma gaubae* Bornm. | 2 | 2 | 3 | 1 | EN | 0.5 |
| *Onosma hebebulba* DC. | 0 | 1 | 0 | 0 | LC | 0.16 |
| *Onosma iranshahrini* Ghahreman et Attar | 3 | 2 | 3 | 1 | CR | 1 |
| *Onosma kerendica* Attar et Mirtadz. | 3 | 2 | 3 | 1 | CR | 1 |
| *Onosma khorassanica* Attar et Joharchi | 3 | 2 | 3 | 1 | CR | 1 |
| *Onosma khorramabadensis* Attar, Mirtadz. et Sotoodeh | 3 | 2 | 3 | 1 | CR | 1 |
| *Onosma kilouyense* Boiss. et Hausskn. | 0 | 0 | 2 | 2 | LC | 0.05 |
| *Onosma kotschyi* Boiss. | 0 | 0 | 1 | 3 | LC | 0.06 |
| *Onosma kurdica* Teppner. | 3 | 2 | 3 | 1 | CR | 1 |
| *Onosma longiloba* Bge. | 1 | 1 | 0 | 0 | VU | 0.16 |
| *Onosma lorestanica* Attar et Sotoodeh | 3 | 2 | 3 | 1 | CR | 1 |
| *Onosma macrophylla* Bornm. | 0 | 0 | 0 | 0 | LC | 0.05 |
| *Onosma maculate* Ranjbar et Almasi | 0 | 1 | 3 | 1 | LC | 0.12 |
| Species                      | IUCN score | Rarity score | Endemism score | Endemism chorology | The extent of occurrence (EOO) | RI |
|------------------------------|------------|--------------|----------------|--------------------|--------------------------------|----|
| *Onosma marivanensis* Mozaff. et Mehrabian | 3          | 2            | 3              | 1                  | CR 1                           |    |
| *Onosma microcarpa* DC.      | 0          | 0            | 0              | 0                  | LC 0.02                         |    |
| *Onosma mousavi* Mehrabian et Amini Rad | 3          | 2            | 3              | 1                  | CR 1                           |    |
| *Onosma mozaffariani* Mehrabian | 3          | 2            | 3              | 1                  | CR 1                           |    |
| *Onosma nervosa* H. Riedl.   | 1          | 1            | 0              | 0                  | VU 0.16                         |    |
| *Onosma olivieri* Boiss.     | 1          | 1            | 0              | 0                  | VU 0.25                         |    |
| *Onosma pachypoda* Boiss.    | 0          | 0            | 3              | 1                  | LC 0.07                         |    |
| *Onosma platyphylla* H. Riedl | 0          | 1            | 3              | 1                  | LC 0.12                         |    |
| *Onosma rasmeyehana* Boiss.  | 0          | 0            | 0              | 0                  | LC 0.07                         |    |
| *Onosma rostellata* Lehmg.   | 0          | 0            | 0              | 0                  | LC 0.08                         |    |
| *Onosma dubianica* Ponert.   | 2          | 2            | 3              | 1                  | EN 0.5                          |    |
| *Onosma sahandica* Attar et Sotoodeh | 3          | 2            | 3              | 1                  | CR 1                           |    |
| *Onosma sanandajensis* Mehrabian et Mozaff. | 3          | 2            | 3              | 1                  | CR 1                           |    |
| *Onosma sarvestanic* Mozaff. et Mehrabian | 2          | 2            | 3              | 1                  | EN 0.5                          |    |
| *Onosma sericea* Willd.      | 0          | 0            | 0              | 0                  | LC 0.03                         |    |
| *Onosma sheidai* Mehrabian.  | 3          | 2            | 3              | 1                  | CR 1                           |    |
| *Onosma stenosiphon* Boiss.  | 0          | 0            | 0              | 0                  | LC 0.04                         |    |
| *Onosma straussii* Riedl Khatamsaz | 0          | 0            | 1              | 3                  | LC 0.08                         |    |
| *Onosma subsericea* Freyn    | 0          | 1            | 0              | 0                  | LC 0.16                         |    |
| *Onosma targevarensis* Mozaff. et Mehrabian | 3          | 2            | 3              | 1                  | CR 1                           |    |
| *Onosma wendelboi* Mehrabian et Mozaff. | 3          | 2            | 3              | 1                  | CR 1                           |    |
| *Onosma zagrica* Dehshiri     | 3          | 2            | 3              | 1                  | CR 1                           |    |