

DISTRIBUTION PATTERNS OF THE GENUS *COUSINIA* (ASTERACEAE) IN IRAN

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The geographical distribution of the genus *Cousinia* in Iran has been analyzed using a dataset of 3095 georeferenced observations. The 241 species of the genus are distributed throughout Iran. However, about third of the observations are made from provinces like, Khorasan Razavi, Tehran, and Fars. The genus has 135 rare species and 197 endemic species. The maximum distance between two observations of the same species, (MaxD) is 1863 kilometers. Razavi Khorasan, Lorestan, Esfahan, North Khorasan and Tehran have the highest number of rare species. Species richness was mapped with the point-to-grid richness analysis tool DIVA-GIS, using a 10×10 kilometer grid cell and the circular neighborhood option with a 50 km radius. High species richness occurs in large area in North of Semnan province, Dena Mountains, Central Alborz, Lorestan province, NW Iran and also in Kopet Dagh Mountain in Khorasan where the hotspots for endemic species are located. Forty five 0.5°×0.5° grid cells are needed to capture all species at once, which have the most conservative importance for this group of plants.

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Key words. *Cousinia*, Iran, geographical distribution, species richness, grid cell.

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پراکنش جغرافیایی جنس کوزینیا در ایران با استفاده از ۳۰۹۵ گزارش ثبت شده در منابع و یا بر اساس نمونه‌های هرباریومی واکاوی گردید. ۲۴۱ گونه این جنس در تمام کشور گسترده اند، هرچند که حدود یک سوم از گزارش‌ها از استان‌های خراسان رضوی، تهران و فارس می‌باشد. این جنس ۱۳۵ گونه نادر و ۱۹۷ گونه انحصاری دارد. بیشترین مقدار برای شاخص حداکثر فاصله میان دو فرد از یک گونه (MaxD) ۱۸۶۳ کیلومتر می‌باشد. استان‌های خراسان رضوی، لرستان، اصفهان، خراسان شمالی و تهران بالاترین تعداد گونه‌های نادر را دارند. به کمک برنامه DIVA-GIS و با استفاده از خانه‌های ۱۰×۱۰ کیلومتر و محدوده دایره‌ای همسایه با شعاع ۵۰ کیلومتر غنای گونه‌ای ترسیم شد. غنای گونه‌ای بالا در زاگرس مرکزی (اساساً استان‌های لرستان، مرکزی و همدان)، البرز مرکزی، شمال غرب ایران و همچنین کوه‌های کپه داغ در خراسان که نقطه داغ گونه‌های انحصاری نیز می‌باشد، مشاهده شد. چهل و پنج خانه ۰/۵×۰/۵ درجه لازم است تا تمام گونه‌های این جنس را در بر بگیرد. این خانه‌ها از لحاظ حفاظتی اهمیت بالایی دارند.

Introduction

A central goal of biogeography and ecology is to discover and understand distributional patterns of organisms (Wu 1991; Axelrod et al. 1998). Perhaps the most important biological challenge today is the

conservation of biodiversity. As human population increases, so does the need for natural resources and space for the growing population (Sigrist & Carvalho 2008). Evidence suggests that during the last millennium, man exploitation of nature has led to an

exponential loss in plant biodiversity and also in the variations existing within communities, species and genes (Hawkes et al. 2000). For example, approximately 34,000 plant species, from an estimated worldwide total of 270,000, are currently facing extinction (Walter and Gillett 1998). To conserve biological diversity, we must first understand the distribution of organisms and how and why these organisms are geographically distributed as they are (Sigrist & Carvalho 2008). Biogeography, the study of the distribution patterns of organisms, is an important tool for this challenge (Sigrist & Carvalho 2008).

Iran is well known for its high diversity in flowering plant flora, with total number of ca. 8000 species, of which ca. 1800 are endemic (Ghahreman & Attar 1999). This is also reflected by the species richness in the genus *Cousinia* Cass. *Cousinia* with about 700 species (Tscherneva 1962; Rechinger 1972, 1979 & 1986; Attar & Ghahreman, 2006; Susanna & Garcia-Jacas 2006) is one of the most diverse genera in central and SW Asia. *Cousinia* is not only of the largest genus of *Asteraceae* but also the largest in the *Arctium* group of the tribe *Cardueae*, subtribe *Carduinae* (Mabberley 1990; Haffner 2000; Susanna et al. 2003). *Cousinia* has more than 400 species in SW Asia, out of which 379 are endemics, distributed in mountainous regions of Iran, Afghanistan and Turkmenistan (Rechinger 1986; Knapp 1987). *Cousinia* is represented by more than 200 species mainly in mountainous areas of Iran (Rechinger 1986; Knapp 1987; Attar & Ghahreman 2006). Since the publication of Flora Iranica number 90, in 1972 (Rechinger 1972) and its supplement in 1979 (Rechinger 1979), many new species have been described, and some synonyms have been used, so that the exact number of species in Iran is still unknown (Mehregan & Kadereit 2008; Assadi 2009; Attar & Mirtadzadini 2009; Djavadi & Attar 2009; Mehregan & Assadi 2009; Attar & Djavadi 2010). A total of 220 species are reported to be found in Iran (Rechinger 1972, 1979). With recent extensive collections and investigations, the number of species has increased to ca. 250, out of which nearly 200 species are endemic (Djavadi et al. 2007).

Geographic Information System (GIS) has recently improved the technology which facilitates the analysis of exploration, gene banks and herbaria databases and elucidates the genetic, ecological and geographic patterns of crops and wild species distribution. DIVA-GIS, technologies are designed to assist scientists in mapping the plant genetic resources, biodiversity communities and the range of distribution of species of interest to them (Hijmans et al. 2002a). GIS has been used successfully by many in identifying areas of high diversity of Phaseolus bean (Jones et al. 1997); wild

potatoes (Hijmans et al. 2000) and piper (Parthasarathy et al. 2006). Considering the importance of *Cousinia*, we have used DIVA-GIS tool to generate maps of both its distribution and diversity for the purpose of exploration and conservation in Iran. We have computed the province- and species-level statistics. For each species, we have estimated the geographic area over which the species occurs and have mapped the number of observations and species richness, using grid cells. We have determined the minimum number of grid cells needed to include all species. Species richness is used because it is a simple, widely used, well-understood, and is a useful measure of taxonomic diversity (Gaston 1996) and is also less sensitive than diversity indices to the problems of unsystematic sampling intensities and procedures (Hijmans et al. 2000). This type of study can provide baseline data for further GIS analysis used for exploration, conservation, and also for germplasm preparation of the selected species, as well as for studies of the factors that determine the geographic distribution of these species (Guarino et al. 2002).

Materials and Methods

A database was compiled that included all species of *Cousinia* known in Iran primarily based on the Flora Iranica (Rechinger 1972, 1979) and on information provide by recent published articles pertinent to the flora of Iran (Akhani 1996; Assadi 2009, 2010, 2011; Attar 2010, 2011; Attar & Djavadi 2010; Attar et al. 2004, 2005; Attar & Maroofi 2010; Attar & Mirtadzadini 2009; Djavadi 2005; Djavadi & Attar 2006; Djavadi & Attar 2009; Djavadi et al. 2007a, 2007b; Ghahreman et al. 1999, 2006; López-Vinyallonga et al. 2009; Mehregan 2008; Mehregan 2011a, 2011b; Mehregan & Assadi 2009; Mehregan & Kadereit 2008; Mehregan et al. 2003, 2010; Memariani & Joharchi 2011; Mirtadzadini & Attar 2004; Mirtadzadini et al. 2004; Sheidai et al. 2006; Susanna et al. 2003). In addition, we used distribution data from the herbarium specimens of Shiraz and Ferdowsi Universities. The data were integrated into Microsoft ACCESS databases. We used Google Earth to georeference the locations. The dataset used in this analysis contained 3095 accurately geo-referenced entries. The number of observations and species in the database were tabulated against province (31 provinces) (Fig. 1). The number of observations per species were calculated and plotted. The average number of observations per species was calculated to assess the intensity of collection by province; given the species richness it harbors (Hijmans & Spooner 2001). For each species, the area over which it occurs was estimated, using two types of statistics: (1) Maximum

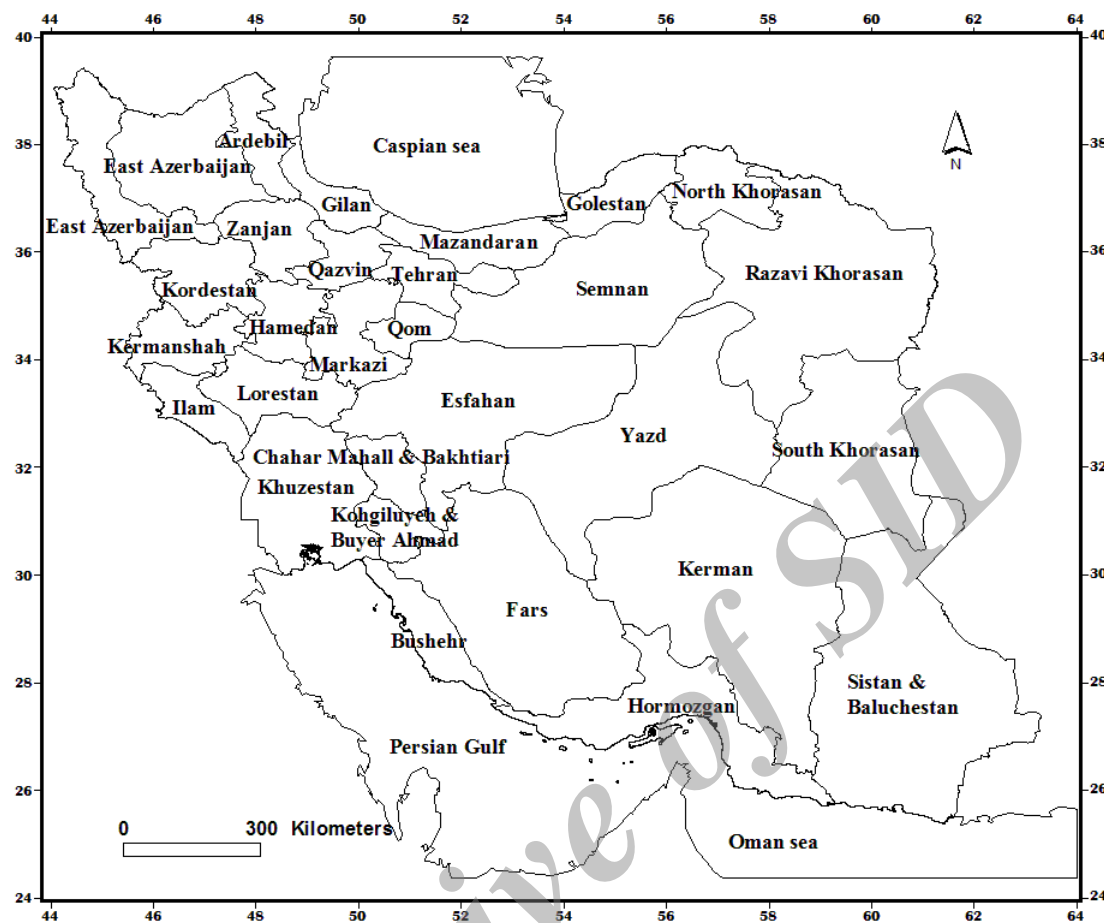


Fig. 1. Iran and its thirty one provinces.

distance (MaxD) between two observations of a single species was calculated as the largest distance (in kilometers) between all possible pairs of observations of one species. (2) We assigned a circular area (CA_{50}) with a radius of 50 km to each observation and calculated the total area of all circles per species. Areas where circles of a species overlapped were only included once. The CA_{50} statistic was plotted against the number of observations to determine the differences in abundance among species. A species with a relatively high number of observations per CA_{50} would be abundant within its area of distribution, whereas a low number would indicate that a species was more scattered over the range in which it occurs (Hijmans & Spooner 2001). To describe species distributions we used the terms “endemic” and “rare.” The term “endemic” was used for species that restricted to Iran and the term “rare” was used for species that had been observed in relatively few (here defined as species with

five or fewer observations) cases. We compared the number of observations and species using a grid with 10×10 km cells (using the point-to-grid richness analysis tool in DIVA-GIS). To eliminate border effects caused by the assignment of the grid origin (Bonham-Carter 1994; Cressie 1991) and to become a smoother surface and yielding results less sensitive to small changes (errors) in the coordinate data (Hijmans & Spooner 2001), we used circular neighborhood with a radius of 50 km. The grid cells in this manuscript are referred, to circles with an area of $\pi r^2 = 7854 \text{ km}^2$ with their center in the middle of the grid cells making up an area of 100 km^2 . In order to determine the optimal locations for optimal reserve thus conserving maximum species diversity, we identified the smallest area (number of grid cells) needed to capture all *Cousinia* species. The species complementarity procedure was based on the algorithm described by Rebelo (Rebelo 1994., Rebelo and Siegfried 1992) and was applied in

Table 1. Number of observations, species, rare species and ratio of observation vs. species per province.

Province	Obs	Species	Rare species	Obs/Species
Alborz	118	20	2	5.9
Ardabil	27	9	0	3
Bushehr	0	0	0	0
Chahrmahal and Bakhtiari	73	20	8	3.65
East Azerbaijan	140	28	7	5
Esfahan	154	35	12	4.4
Fars	234	29	7	8.06
Gilan	31	14	6	2.21
Golestan	46	20	2	2.30
Hamadan	115	20	5	5.75
Hormozgan	2	2	0	1
Ilam	7	1	0	7
Kerman	64	22	9	2.9
Kermanshah	64	14	2	4.57
Khuzestan	5	5	1	1
Kohgiluyeh and Boyer-Ahmad	24	13	6	1.84
Kordestan	123	21	5	6.1
Lorestan	140	27	10	5.18
Markazi	92	20	5	4.6
Mazandaran	94	27	9	3.48
North Khorasan	190	40	13	4.75
Qazvin	47	11	6	4.27
Qom	13	6	0	2.16
Khorasan Razavi	622	76	34	8.18
Semnan	144	30	6	4.8
Sistan and Baluchestan	33	5	0	6.6
South Khorasan	52	18	7	2.88
Tehran	231	34	10	6.79
West Azerbaijan	140	26	7	5.38
Yazd	28	11	1	2.54
Zanjan	40	12	2	3.33
Total	3095			

the DIVA-GIS software that selects grid cells which identifies the minimum set of cells that captures the maximum number of species. The process is iterative, whereby the first iteration is the most species rich and the second is the richest grid cell in species which are not represented in the first iteration and so on, until all species have been represented. We determined the minimum number of grid cells needed to include all species.

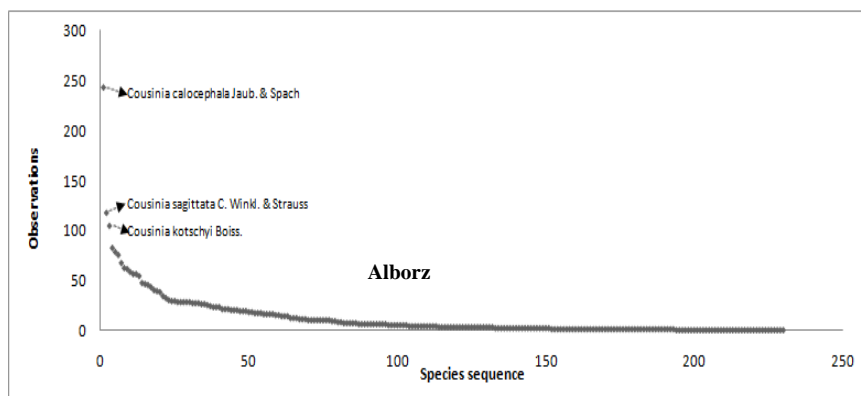
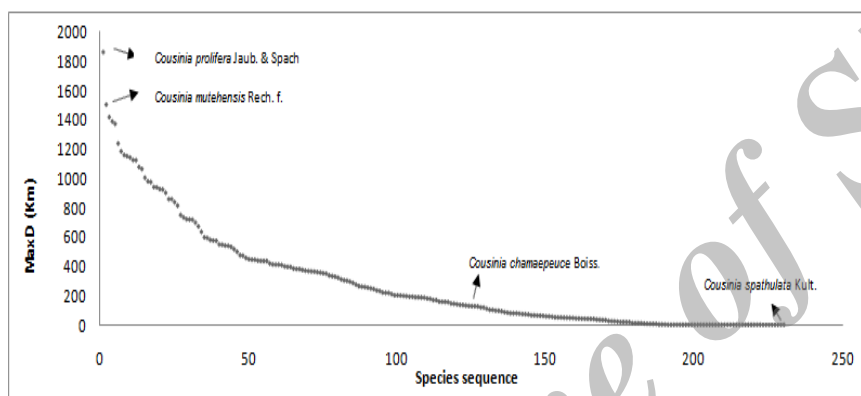
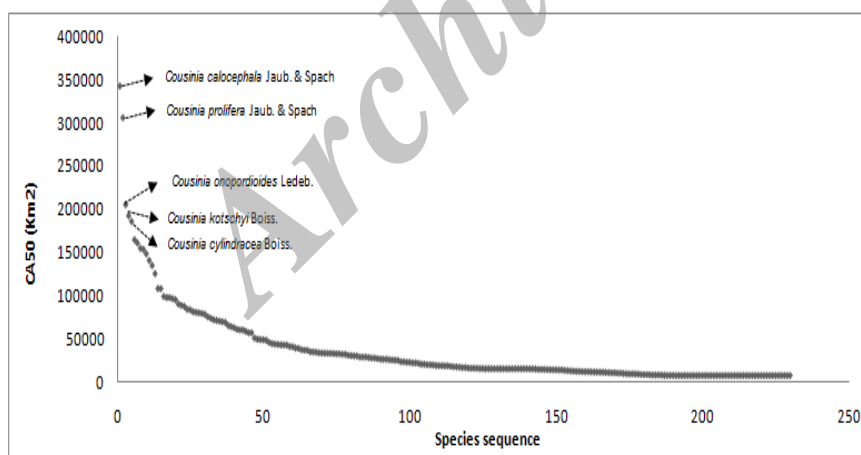
Results

A total of 3095 georeferenced datasets were added to Shiraz University Herbarium database. Based on the databases, the *Cousinia* has 42 sections and approximately 241 species in Iran. Some largest sections are: *Cynaroideae* with 39 species, *Stenocephalae* with 31 species, *Serratuloideae* with 18

species and *Pugioniferae* with 14 species. Some species are widely distributed, while others are endemic to relatively small regions.

Members of the *Cousinia* genus are found in 30 of 31 provinces in Iran (Table 1), One third of the observations are reported from just three provinces (Razavi Khorasan, Tehran and Fars). Razavi Khorasan province, accounts for some 20% of the records in the database. This province has also the highest number of species. The highest numbers of rare species are found in Razavi Khorasan Province comprising of 34 rare species, which occur only in this province.

The distribution of the number of observation by species is far from uniform (Fig. 2). Only 19 species have an observation number of above 40. The most frequently observed species are *C. calocephala* Jaub. & Spach (243 observations), *C. sagittata* C. Winkl. &

Fig. 2. Number of observations of *Cousinia* by species.Fig. 3. Maximum distance between two observations of one *Cousinia* species (MaxD).Fig. 4. Circular area CA_{50} of *Cousinia* species. A circular area with a 50 km radius was assigned to each observation.

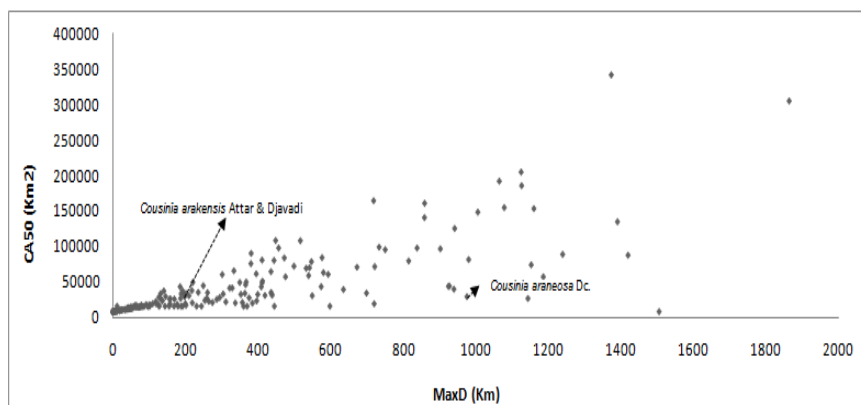


Fig. 5. Circular area (CA_{50}) vs. number of observations of *Cousinia* species. Each dot refers to one species. A circular area with a 50 km radius was assigned to each observation.

Strauss (118 observations), *C. kotschy* Boiss. (105 observations), *C. onopordioides* Ledeb. (83 observations), *Cousinia prolifera* Jaub. & Spach (79 observations). These five species account for 20.3% of the records. The entire 135 rare species (56% of all species) make up only about 11% of the observations. The ratio between the observations and the species numbers varies strongly across provinces (Table 1). Tehran province has the highest ratio. The ratio is low in many provinces; most of them have low to average species richness. Nonetheless, there are some provinces in this group that have high species richness, such as Golestan and Kerman provinces. Since the number of species tends to increase with the increase in collection attempts, the provinces with a low ratio between species and observations would be the most likely places to find species that have not yet been explored intensively (Hijmans & Spooner 2001). Bushehr, Hormozgan, Ilam, Khuzestan, Qom and Yazd are some examples of such provinces (Table 1).

Most of the *Cousinia* species are endemics. *Cousinia calocephala* Jaub. & Spach is the only species that occurs in 14 provinces, followed by *Cousinia cylindracea* Boiss. which occurs in 13 provinces. The average longest distance between two observations of the same species (MaxD) is 291 km. For 149 species, MaxD is <291 km, which indicates 62% of the total species have a MaxD lower than the average (Fig. 3). The longest MaxD observed was for *Cousinia prolifera* Jaub. & Spach (1863 km). The average circular area (CA_{50}) for all species is 36777 km² and the distribution of which is strongly skewed (Fig. 4). More than half of the total species (69%) have a CA_{50} of less than the average.

To compare the species abundance in their areas of distribution, we plotted the CA_{50} against the number of

observation (RCA_{50}) calculated as $CA_{50}/\text{number of observations for each species}$ (Fig. 5). A species with a high number of observations per CA_{50} would be considered as an abundant within its area of distribution (or densely populated), like *C. araneosa* DC., which has the lowest RCA_{50} , whereas, a low number would indicate that a species has a more scattered distribution within the range in which it occurs (or less densely populated), such as *Cousinia triflora* Schrenk which has the highest RCA_{50} among all species (Fig. 5).

Obviously, circular area goes up with the number of observations (Fig. 5). There are, however, important differences among species. As shown in Fig. 5 one species, *C. araneosa* is conspicuously out of the mentioned pattern, which is due to its high observation number. For example, *C. keredjensis* Attar & Djavadi and *C. komarowii* C. Winkl. occur in an area of comparable size, but *C. araneosa* has been observed about 5 times more often, suggesting that *C. araneosa* is much more abundant (note that comparison is made between two species with different collection interest). Since provinces are of different shapes and sizes, the grid based maps showing the number of observations (Fig. 6) and species richness (Fig. 7) give a much more clear picture than the province summaries presented in Table 1. Species richness is clearly not homogeneously distributed within provinces. There are few areas with many species, and many areas with few species (Figs. 6, 7). In Iran, areas of species richness hotspots are: (1) mountainous areas of Kopetdagh; (2) a broad region in the Central Alborz mountains; (3) Lorestan province (4) Dena mountains; (5) a large area in North of Semnan province; (Fig. 7). Three of the total five species rich areas (areas 1, 2 and 3) are overlapped with the areas of high observations (compare Figs. 6 and 7). Unlike the three areas mentioned before, areas 4

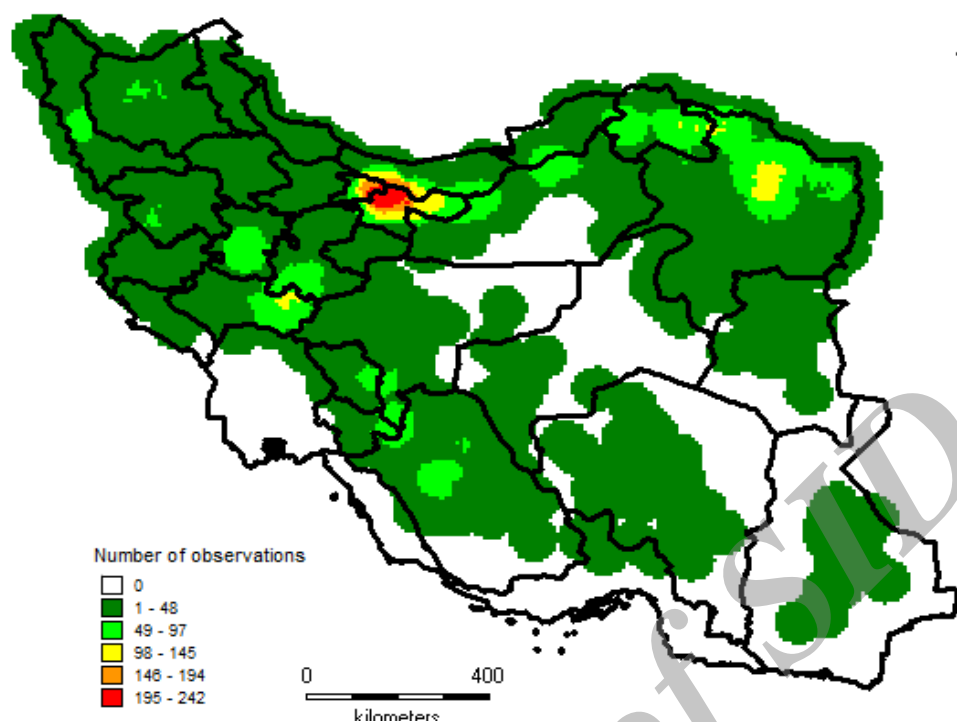


Fig. 6. Number of observations of *Cousinia* species per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

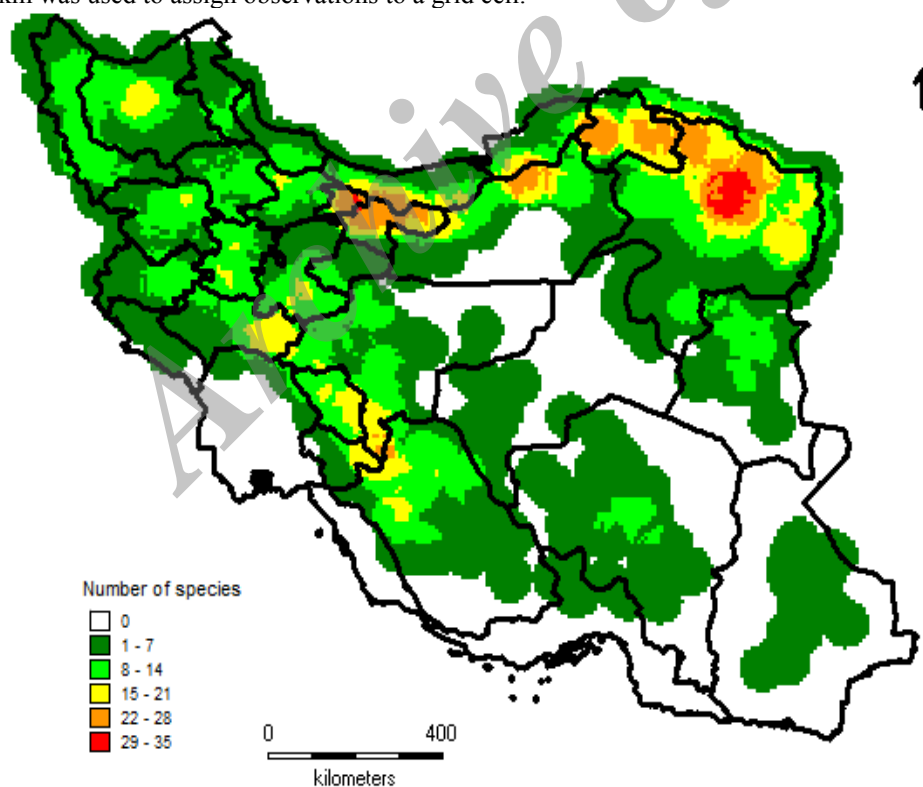


Fig. 7. Number of *Cousinia* species per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

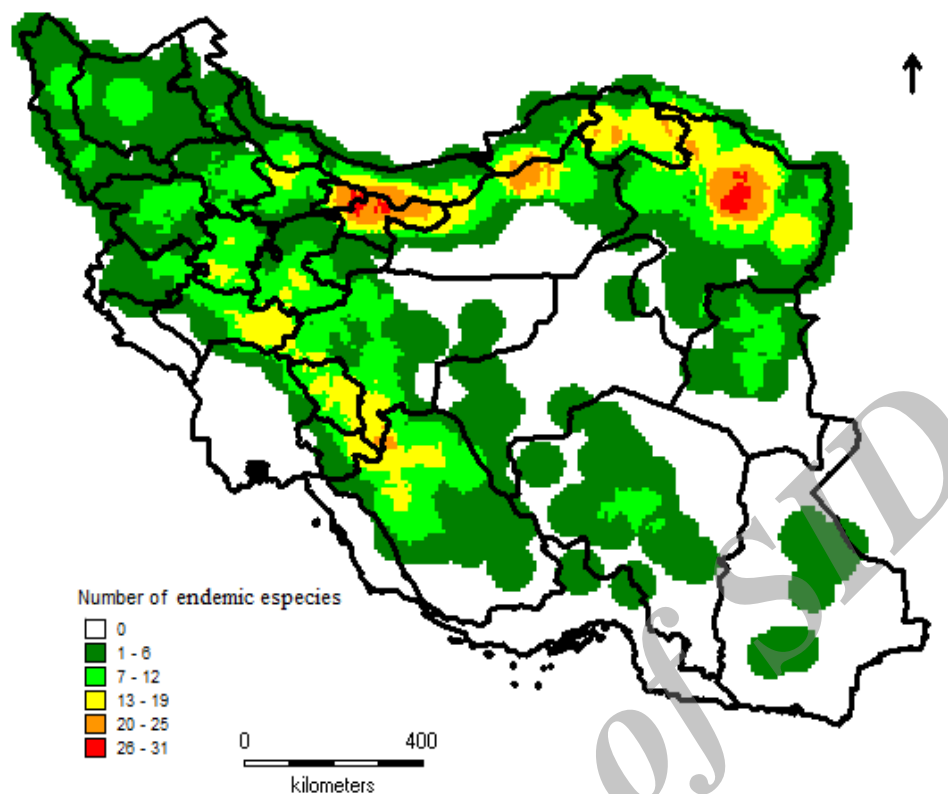


Fig. 8. Number of *Cousinia* endemic species per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

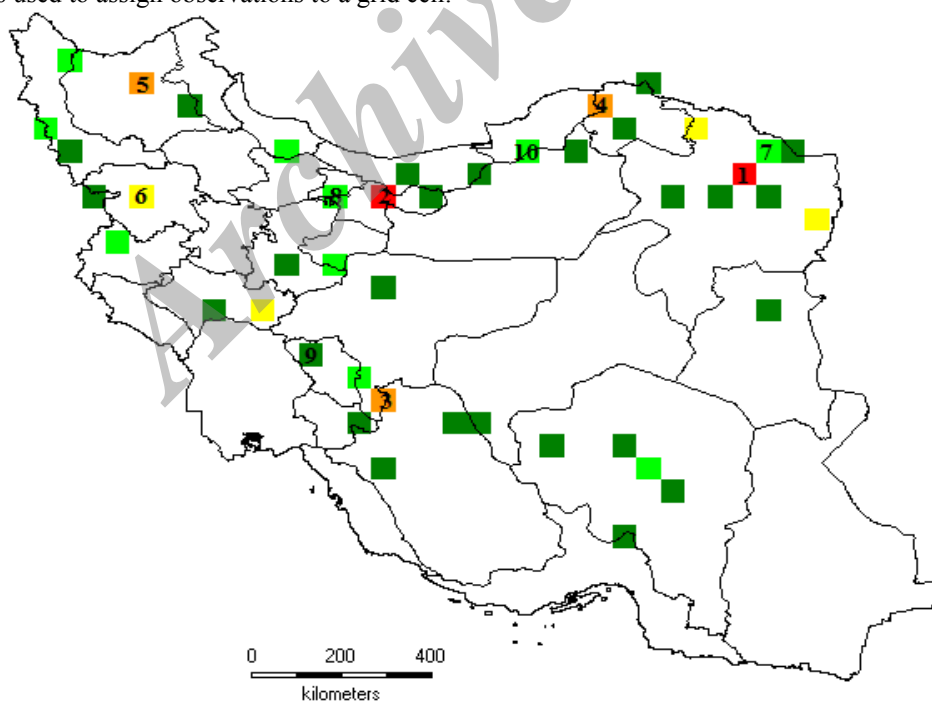


Fig. 9. The location of the first 10 grid cells selected and locations of the other 35 grid cells needed to include *Cousinia* species in Iran.

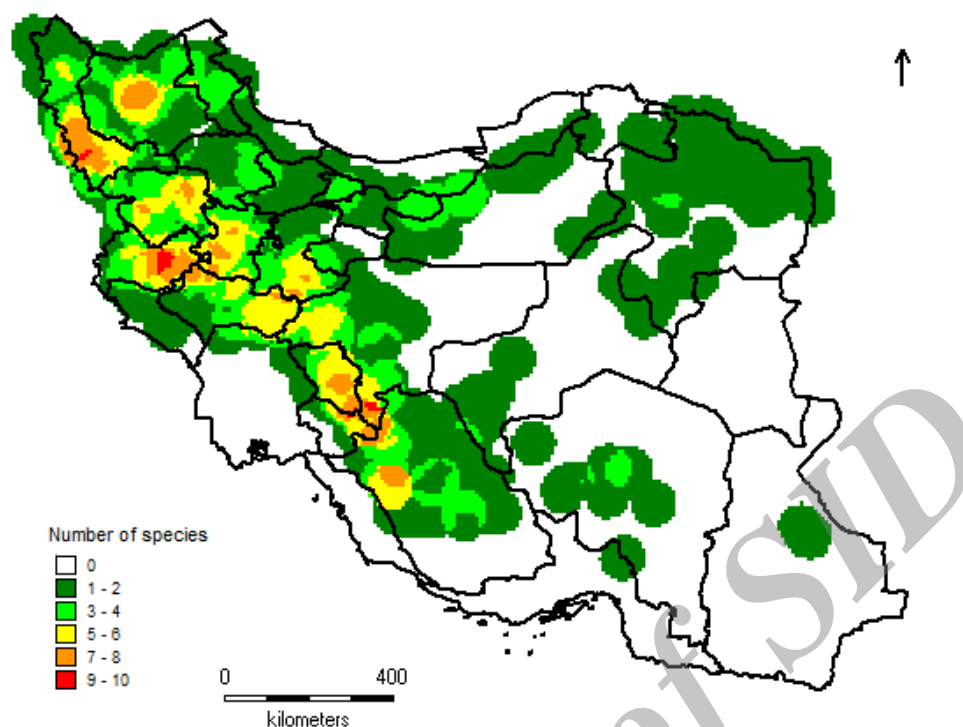


Fig. 10. Number of species of *Cousinia* section *Cynaroideae* per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

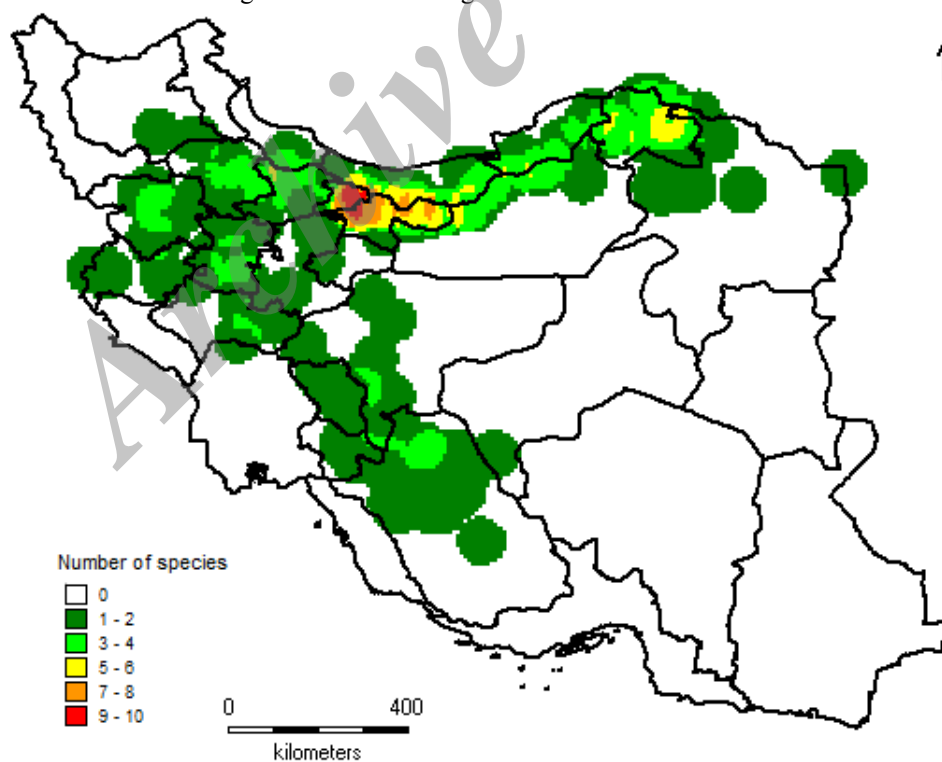


Fig. 11. Number of species of *Cousinia* section *Stenocephalae* per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

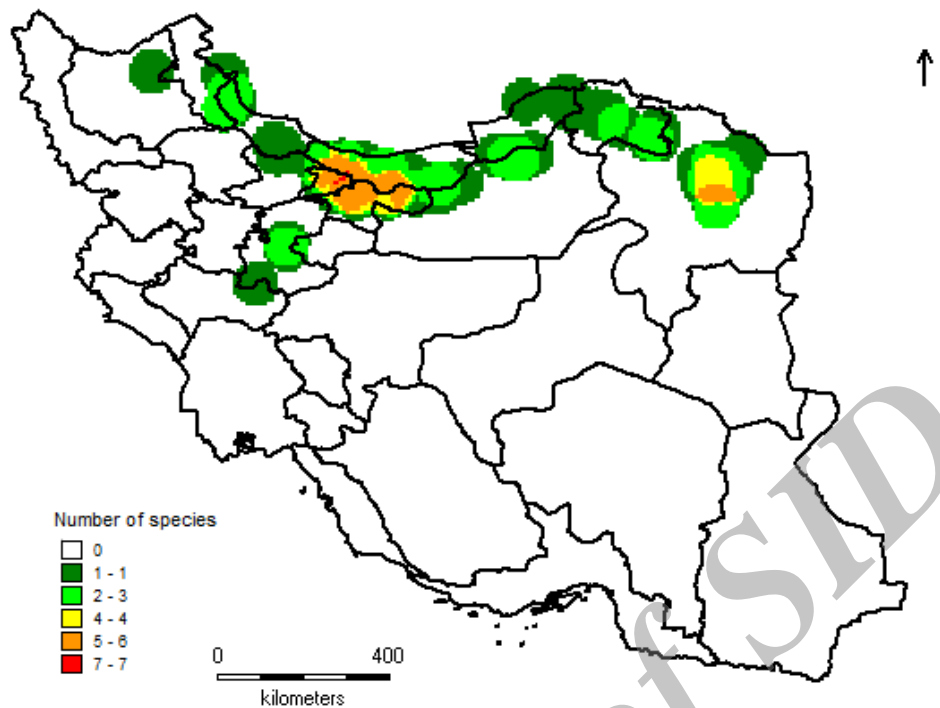


Fig. 12. Number of species of *Cousinia* section *Serratuloidea* per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

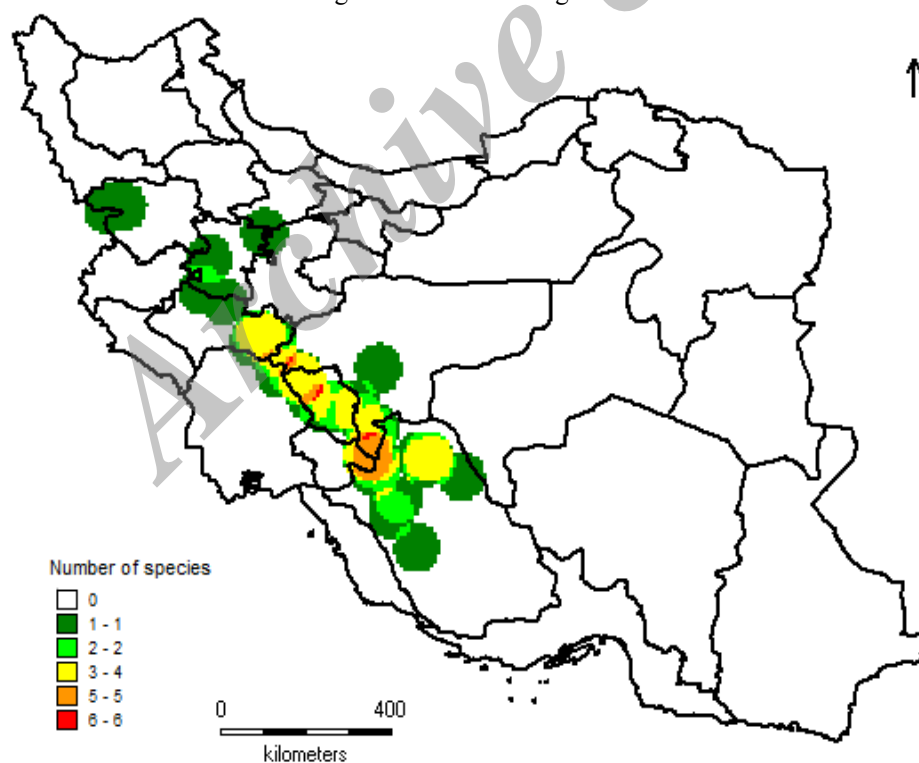


Fig. 12. Number of species of *Cousinia* section *Albidae* per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

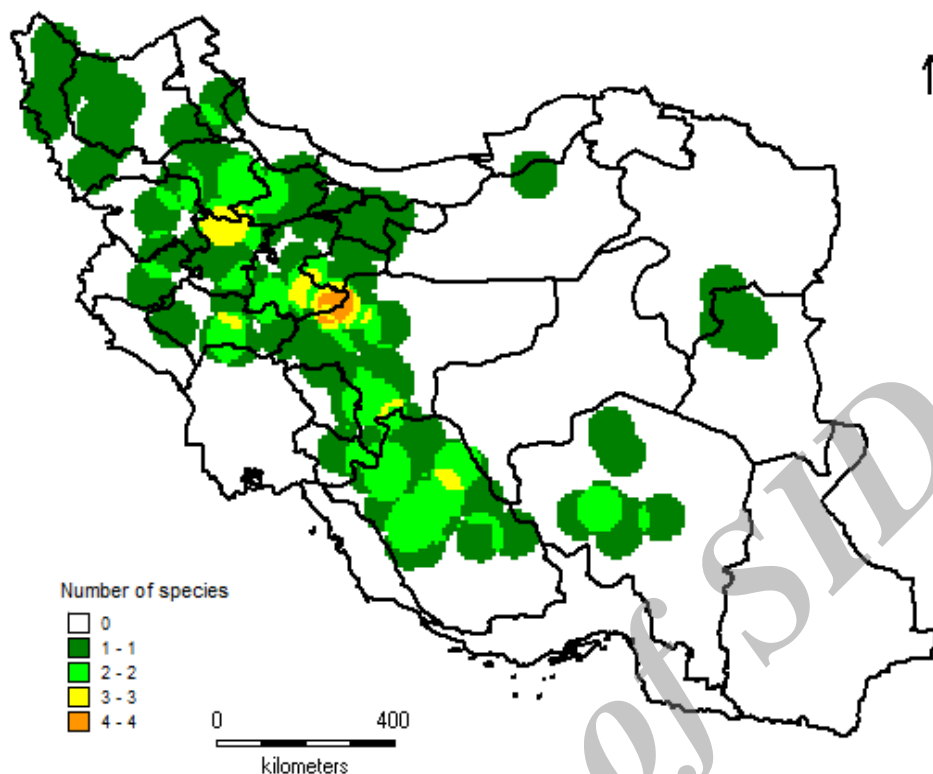


Fig. 12. Number of species of *Cousinia* section *Pugioniferae* per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

and 5 which are located in Dena Mountains and Semnan provinces, does not correspond to areas with high collection. It seems that these hotspots are really one of the most species rich areas.

We also mapped the endemic species richness. The hotspot of the endemic species is located in the Razavi Khorasan, the first hotspot area for all species (Figs. 7 and 8). Also areas in Dena Mountains, Golestan National Park, Central Alborz, North of Semnan provinces have high number of endemic species.

Although 10 grid cells located in East Azarbaijan, Chaharmahal and Bakhtiari, Fars, Golestan, Kurdistan, North Khorasan, Razavi Khorasan and Tehran provinces are enough to collect 60% of all *Cousinia*, a minimum number of Forty five grid cells are needed to collect all species at least once (Fig. 9).

Discussion

In this study, for the first time, the species distribution of the genus *Cousinia* in Iran are systematically analyzed, using GIS. In Iran, species richness of *Cousinia* is particularly high in the Kopet Dagh mountains range, Central Alborz and Dena Mountains. The mountain ranges of Kopet Dagh have a high

number of *Cousinia* species as well as a high number of rare *Cousinia* species.

Since conservation founding's are limited, we preferred to use 10×10 km grid size to define smaller areas for conservation. Many *Cousinia* species are narrowly endemic, and yet a selection of forty five grid cells was needed to include all the species, which emphasizes the presence of areas of high species richness. The most species-rich grid cell has a high percentage of all species. This might facilitate the design of in situ conservation reserves to protect these species.

Our data were gathered from several sources (expeditions) and this may have led to some redundancies. Particularly type localities of rare species were visited by different expeditions, as these species may not be found elsewhere. Hence, some of these species are even more rare and endemic than shown by our data. Overall, however, it may make our data more reliable given the time dependency of the results of *Cousinia* exploration: the likelihood of finding certain species in certain locations will differ within or among the years. Some of our data have been recorded recently, but many data are not new and date back for

many years (mentioned only in the available Floras). Even in some cases, the habitat in which the species used to occur has now disappeared, and may no longer be found there. But these discrepancies have not much effect on the whole results (Hijmans et al. 2002b).

Cousinia is unevenly distributed in SW and central Asia. Eight major centers of species diversity have been defined for the genus in Southwest and Central Asia. The most important center of species diversity is situated in Pamir- Alay range in the Middle Asia with ca. 170 species, of which 130 are endemics (Knapp, 1987). Khorassan-Kopetdagh floristic province in NE Iran and S Turkmenistan can be considered as the second important center of the diversification of *Cousinia* inhabited by approximately 100 species, of which 70 species are endemic to the area (Rechinger, 1972, 1979).

Some sections are widely distributed, while others are endemic to relatively small regions. Section *Cynaroides* Bunge with 110 published species is the largest section of the genus. It is distributed in Lebanon, Syria, Turkey, the Caucasus, Iraq, Iran, Turkmenistan, Afghanistan and Pakistan, with centers of specific diversity mainly in W and NW Iran, N Iraq and SE Turkey (Mehregan & Kadereit, 2008). All species belonging to the section are Irano-Turkestanian elements (Rechinger 1986) and mostly have a very limited distribution area and occupy very small isolated places. Towards the east, the number of species of the section decreases. Towards the west, the number of species of the section decreases, so that Iraq and Turkey each has 17 and 8 species respectively (Attar & Ghahreman, 2006). Pakistan with only one species is the poorest country regarding the species richness in the section *Cynaroides* (Attar & Djavadi 2010). In the strict sense, section *Cynaroides* has 39 species in Iran (Mehregan & Kadereit 2008). Our analysis shows the most of the Iranian species are found in Zagros mountain ranges (Fig.10). Towards the east, the number of species is so sharply reduced (Fig.10). Section *Stenocephalae* has more than 31 species most of which are endemic to Iran (Fig. 11). This section is the second largest after *Cynaroideae* Bunge in the genus *Cousinia* in Iran. The section is distributed in southwestern Asia; it seems that Iran is the center of its diversity and origin (Ghaffari & Djavadi, 1998). Iran shares two species with Turkmenistan (*Cousinia stahlianiana* Bornm. & Gauba and *C. hypopolia* Bornm. & Lint) and one with Iraq and Turkey (*C. stenocephala* Boiss.). In addition, four species are endemic to Turkmenistan (Ghaffari & Djavadi, 1998). Our analysis shows the distribution of this section in Iran is mainly in eastern and central parts of Alborz Mountains, central part of Zagros Mountains as well as in North

Khorasan mountains (Fig. 11). *Cousinia* section, *Serratuloideae*, has 18 species in Iran. All species of this section except *C. pterocaulos* are endemic to Iran and mostly are distributed in central Alborz, North Khorasan and Razavi Khorasan provinces (Fig. 12). Section *Albidae* is represented by 13 species in Flora Iranica area. All members of this section are endemic to SW Iran and are distributed in Fars, Lorestan and Bactiari provinces (Attar & Maroofi 2010). General distribution of *Cousinia* Sect. *Pugioniferae* Bunge is in Iran, Turkey, Transcaucasia, Syria, Iraq and Afghanistan. Its diversity center is northwest and west of Iran. This section includes 15 species, of which 13 species occur in Iran (Attar & Mirtadzadini, 2009). Twelve species of this section are endemic to Iran and mostly is distributed in different parts of Iran in Markazi, Lorestan, Hamadan, Fars, Esfahan, Kerman, West Azarbaijan and Zanjan provinces (Fig.14).

Biogeographical variation in species richness and endemic richness is critical to our understanding and conservation of biological diversity. Areas with high species richness may also have a high number of endemic species, but not necessarily in a coherent pattern (Huston, 1994; Whittaker *et al.*, 2001).

In the desert areas (Dasht-e Kavir and Dasht-e Lut) of central Iran, members of *Cousinia* have not been recorded, which are due to poor road networks, very hot climate and security concerns for the travelers.

Although the number of observations per grid cell is a reasonably good predictor of the number of species in that cell, we do not think that a high number of species follows casually by a high number of observations.

Resolution (cell size) of the grid, affects the results. Number of species per grid cell will increase with the size of the grid-cell, but this increase will be different for different areas. We used an equal-area of 10×10 km grid cells (and a circular neighborhood with a radius of 50 km to set up the distribution of the species. Using small grid sizes have a high resolution and low geographic sampling bias.

We used a circular neighborhood to assign values to grid cells because this gives a smoother result, particularly for areas with few observations and is less sensitive to the origin of the grid and small errors in the local data (Cressie, 1991; Bonham-Carter, 1994).

Although Iran seems to be reasonably well explored with respect to number of species over observations, it has an exceptionally high number of apparently rare species. This indicates that Iran may still harbor unknown species. So it is recommended to pay some attention towards these poorly collected areas in the future. Perhaps, further explorations would discover additional species and solve the problem of nonrandom spatial distribution of species observation point

(Maxted et al. 2005).

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