

PATTERNS OF DISTRIBUTION IN THE FAMILY FABACEAE (EXCEPT ASTRAGALUS) IN IRAN

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Received 21.10.2010. Accepted for publication 10.11.2010.

Mousavi, T. S. & Ahmad Reza Khosravi, A. R. 2010 12 31: Patterns of distribution in the family *Fabaceae* (except *Astragalus*) in Iran. –*Iran. J. Bot.* 16 (2): 303-313. Tehran.

The geographic distribution of the family *Fabaceae* (except the genus *Astragalus*) in Iran has been analyzed using a dataset of 10408 georeferenced observations. The 429 species of the family is distributed in whole Iran; however, about half of the observations are from provinces like, Fars, Hormozgan, Tehran, Bushehr and Mazandaran. The family has 173 rare species and 117 endemic species. The highest record for the maximum distance between two observations of one species (MaxD) is 2140 kilometer. East-Azerbaijan, Khorasan Razavi, Fars, Lorestan and West-Azerbaijan 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 Fars, Gilan and Lorestan; also in Central Alborz where the hotspot for endemic species is located. Forty four 10×10 kilometer grid cells are needed to capture all species at once. But ninety percent of the species can be captured in only twenty grid cells, which have the most conservative importance for this group of plants.

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Key words. *Fabaceae*, Iran, geographic distribution, species richness, grid cell.

الگوی پراکندگی تیره باقلائیان (به جز جنس گون) در ایران

طلیعه السادات موسوی، فارغ التحصیل کارشناسی ارشد بخش زیست شناسی دانشگاه شیراز.

احمدرضا خسروی، دانشیار بخش زیست شناسی دانشگاه شیراز.

پراکنش جغرافیایی تیره باقلائیان (به جز جنس گون) در ایران با استفاده از ۱۰۴۰۸ گزارش ثبت شده در منابع ویا بر اساس نمونه‌های هرباریومی تجزیه و تحلیل گردید. ۴۲۹ گونه این تیره در تمام کشور گسترده اند، هرچند که حدود نیمی از گزارش‌ها از پنج استان فارس، هرمزگان، تهران، بوشهر و مازندران می باشد. این خانواده ۱۷۳ گونه نادر و ۱۱۷ گونه انحصاری دارد. بیشترین مقدار برای شاخص حداکثر فاصله میان دو فرد از یک گونه (MaxD) ۲۱۴۰ کیلومتر می‌باشد. استان‌های آذربایجان شرقی، خراسان رضوی، فارس، لرستان و آذربایجان غربی بالاترین تعداد گونه‌های نادر را دارند. به کمک برنامه DIVA-GIS و با استفاده از خانه های ۱۰×۱۰ کیلومتر و محدوده دایره‌ای همسایه با شعاع ۵۰ کیلومتر غنای گونه‌ای نقشه‌برداری شد. غنای گونه‌ای بالا در استان‌های فارس، گیلان، لرستان و همچنین منطقه البرز مرکزی که نقطه داغ گونه‌های انحصاری نیز می‌باشد، مشاهده شد. چهل و چهار خانه ۱۰×۱۰ کیلومتر لازم است تا تمام گونه‌های این تیره را در بر بگیرد. اما بیست خانه کفایت تا نود درصد گونه‌ها را در خود جای دهد، این خانه‌ها از لحاظ حفاظتی اهمیت بالایی دارند.

Introduction

Iran constitutes the largest part of the Iranian Plateau. It has a total surface area of 1.6×10^6 km². Except for the interior deserts and the lowlands along the Caspian Sea, Persian Gulf and Oman Sea, about half of Iran is composed of high mountains (Noroozi et al. 2008).

These mountains have affected Iran's climate, soils and have caused a variation of different climates and vegetation zones. The main mountain chains Alborz (stretching along the coastal zone of the Caspian sea) and Zagros (extending from NW toward SE of Iran) form a natural barrier which inhibits the humid winds

of SW and prevents the majority of clouds from reaching the center, east and south of the country, so Dasht-e Kavir and Dasht-e Lut (deserts) are created in central east of Iran. Besides, it caused a humid climate with a fairly high amount of annual precipitation north of Alborz (Caspian Plain) and slightly Mediterranean climate western Zagros. Moreover, Iran has even sub-tropical climate which belong to south Iran, the coast of the Persian Gulf and Oman Sea but the great part of the country is distinguished by arid continental climate. All these have made a good condition for the tropical, sub-tropical and temperate *Fabaceae* to distribute all over the country. The *Fabaceae* is second only to *Poaceae* in agricultural and economic importance. The family includes many horticultural varieties and many species are harvested as crops. Without counting the genus *Astragalus* L. the *Fabaceae* is the second largest family of angiosperm in Iran (Yousefi 2006). Despite various studies about the selected family, there has been no comprehensive analysis of the geographic distribution of its species, which we provide in this paper. Indeed the paper here provides an overview of the geographic distribution analysis of the family (except the genus *Astragalus*) in Iran.

We used geographic information systems (GIS) to analyze a large georeferenced database of locations where the species were observed. We computed province- and species-level statistics. For each species, we estimated the geographic area over which it occurs and mapped the number of observations and species richness, using grid cells. We 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 useful measure of taxonomic diversity (Gaston 1996) and because it is 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 for exploration, conservation, and use of germplasm of the selected species (Guarino et al. 2002), as well as for studies of the factors that explain the geographic distribution of these species.

Materials and Methods

We gathered distribution data from the Flora Iranica (Chrtkova-Zertova et al., 1979, Rechinger, 1984, Rechinger, 1986a, Rechinger, 1986b) which is the major taxonomic and nomenclatural reference for the project. Additional distribution data are also added from Floras of Iran published by Research Institute of Forests and Rangelands (Pakravan et al. 2000, Ghahremaninejad, 2004, Zaify 1996). For some taxa, information of recent articles has been adopted (Attar et

al. 2004, Amirabadizadeh et al. 2007, Naqinejad et al. 2007, Ghahremaninejad et al. 2008, Amirabadizadeh et al. 2009, Badrzadeh & Ghafarzadeh-namazi 2009, Assadi 1988). In addition, we used distribution data of herbarium records, which includes 2508 of georeferenced data set we used for analyzing. Nearly 85% of the *Fabaceae* herbarium records were identified by our own using the taxonomic keys in various floras (Chrtkova-Zertova et al. 1979, Rechinger 1984, Rechinger 1986a, Rechinger, 1986b, Davis et al. 1988, Townsend & Guest 1974, Ali 1977).

Most of the data sets hadn't coordination. Therefore, we used Google Earth (<http://earth.google.com/>) to georeference the locations. Using Google Earth gave us the possibility virtually recreating the collection trip, using the site description, which identified towns, road names and numbers, and kilometer travelled from town A to town B, using the path ruler (Berger et al. 2008). At the putative collection site, site coordinates were added to the data set. Some 800 specimens from the original database which lacked geographic coordinates were excluded from the database. All geographic coordinates were then subjected to an error checking exercise using Map info. The final data set used in this analysis contained 10408 accurately geo-referenced entries.

The number of observation and species in the database were tabulated by province (30 provinces are defined for Iran) (Fig. 1). The number of observation per species was calculated and plotted. The average number of observations per species was calculated to assess intensity of collection by province, given the species richness it harbors (Hijmans & Spooner 2001). For each species, we estimated the area over which it occurs, using two statistics: (1) Maximum 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 50 km to each observation and calculated the total area of all circles per species. Areas where circles of a species overlap are only included once. The CA_{50} statistic was plotted against the number of observations to explore differences in abundance between 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 use the terms "endemic" and "rare." We use "endemic" for species that occur in relatively small areas (have a small range size) (Rabinowitz 1981; Gaston and Williams 1996) and "rare" for species that have been observed in relatively few cases.

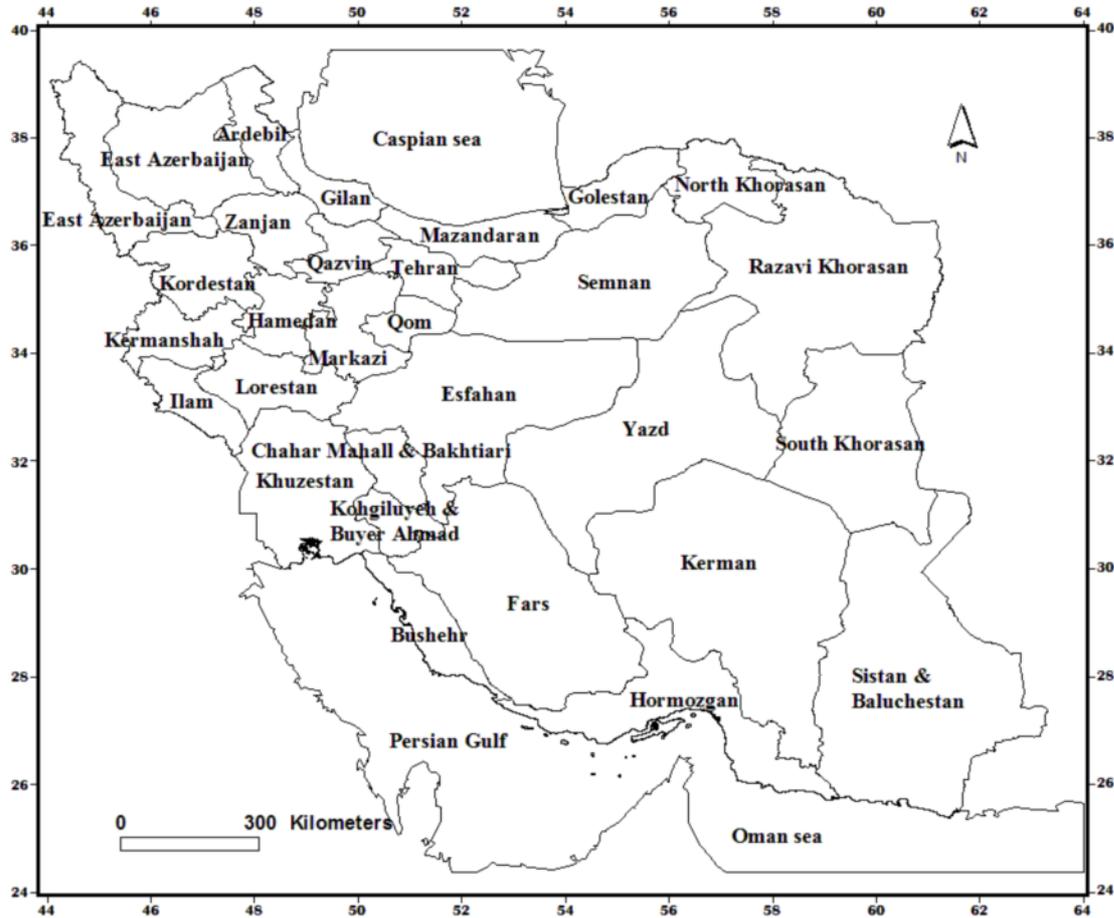


Fig. 1. Iran and its thirty provinces.

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 a result also 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 refer this paper, to circles with an area of $\pi r^2 = 7854$ km² with their center in the middle of the grid cells with an area of 100 km².

To determine optimal locations for optimal reserve to conserve maximum species diversity we identified the smallest area (number of grid cells) needed to capture all *Fabaceae* (except *Astragalus*) species. The species complementarity procedure is based on the algorithm described by Rebelo (Rebelo 1994., Rebelo and Siegfried 1992) and is applied in the DIVA-GIS software that selects grid cells so as to identify the

minimum set of cells that captures a maximum amount 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 and mapped the location of the first 20 grid cells. The grid cell size was defined as 10×10 km.

Results

We recorded a total of 10408 georeferenced data set to Shiraz University's Herbarium data base. A number of 2780 records are extrapolated (added) from the herbarium samples of Shiraz University (Herb. of Shiraz University). According to the data base the *Fabaceae* (excluding *Astragalus*) has 72 genera and approximately 429 species in Iran. Some largest genera are: *Onobrychis* Miller with 56 species, *Vicia* L. with

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

Province	obs	Species	Rare species	obs/species
Ardabil	127	57	7	2.23
Bushehr	671	84	4	7.9
Chahrmahal and Bakhtiari	63	42	0	1.5
East Azerbaijan	415	117	29	3.55
Esfahan	249	75	5	3.32
Fars	2320	154	19	15.1
Gilan	366	95	17	3.85
Golestan	300	88	9	3.41
Hamadan	153	60	3	2.55
Hormozgan	1045	84	16	12.44
Ilam	36	29	1	1.24
Kerman	312	80	11	3.9
Kermanshah	214	82	9	2.61
Khuzestan	403	100	9	4.03
Kohgiluyeh and Boyer-Ahmad	153	65	1	2.35
Kordestan	216	73	9	2.96
Lorestan	395	124	19	3.2
Markazi	95	41	0	2.32
Mazandaran	498	104	17	4.8
North Khorasan	165	70	8	2.36
Qazvin	152	69	7	2.2
Qom	15	11	0	1.36
Khorasan Razavi	270	84	20	3.2
Semnan	194	63	7	3.1
Sistan and Baluchestan	409	71	8	5.8
South Khorasan	18	15	2	1.2
Tehran	692	113	13	6.12
West Azerbaijan	306	102	18	3
Yazd	66	29	4	2.3
Zanjan	90	51	1	1.8
Total	10408			

52 species, *Trifolium* L. with 45 species, *Oxytropis* DC. with 34 species and *Trigonella* L. with 31 species.

Members of the *Fabaceae* family occur in the whole 30 provinces of Iran (Table 1). Half of the observations are reported from just five provinces (Fars, Hormozgan, Tehran, Bushehr and Mazandaran). Fars, the province, which Shiraz is, its center account for some 22% of the records in the data base. It has also the highest number of species. The highest number of rare species (here defined as species with five or fewer observations) belongs to the province East-Azerbaijan with 29 rare species, of which occur only in this province.

The distribution of the number of observation by species is far from uniform (Fig. 2). Only 66 species have an observation above 50. The most frequently observed species are *Ebenus stellata* Boiss. (235 observations), *Vicia sativa* L. (192 observations),

Medicago sativa L. (179 observations), *Glycyrrhiza glabra* L. (173 observations), *Lotus corniculatus* L. (165 observations). This five species account for 10% of the records. The entire 173 rare species (40% of all species) represents only about 3% of the observations.

The ratio between the number of observation and the number of species varies strongly across provinces (Table 1). Fars province has the highest ratio, which is because of the high access we had to our department herbarium. 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 Lorestan province, West and East Azerbaijan provinces. Because the number of species tends to go up with collecting effort, the provinces with a low ratio between species and observation would be the most likely places to find species that have not yet been discovered intensively

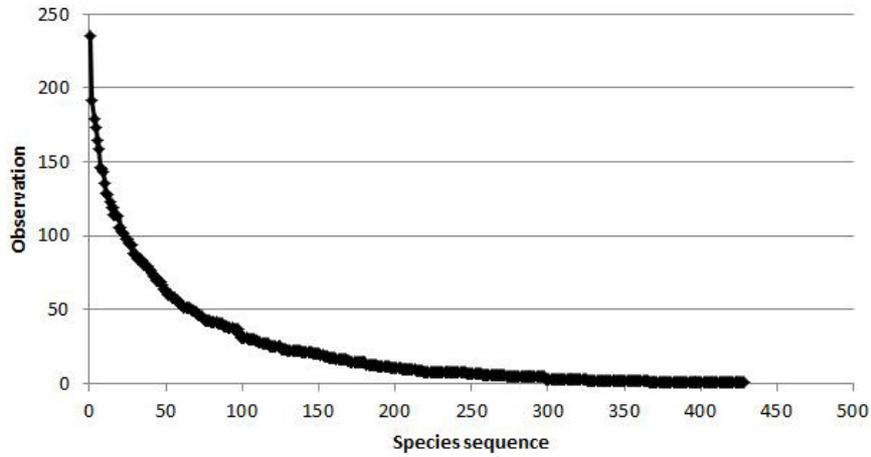


Fig. 2. Number of observations of *Fabaceae* (except *Astragalus*) by species.

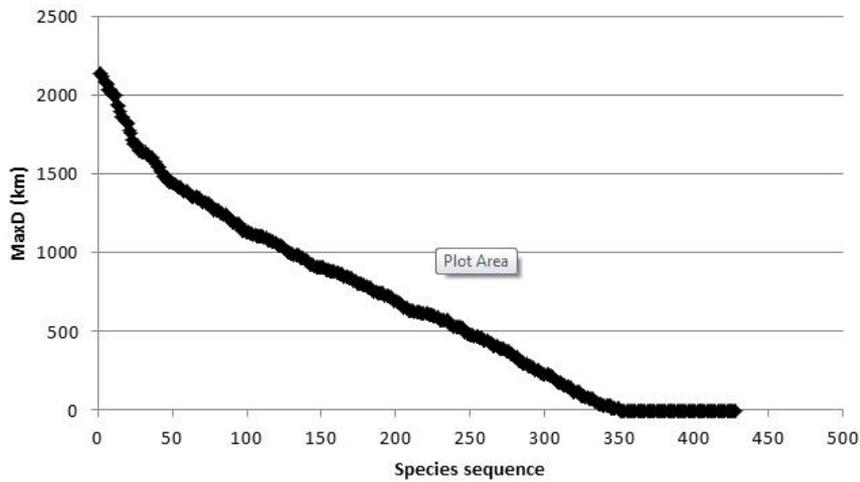


Fig. 3. Maximum distance between two observations of one *Fabaceae* (except *Astragalus*) species (MaxD)

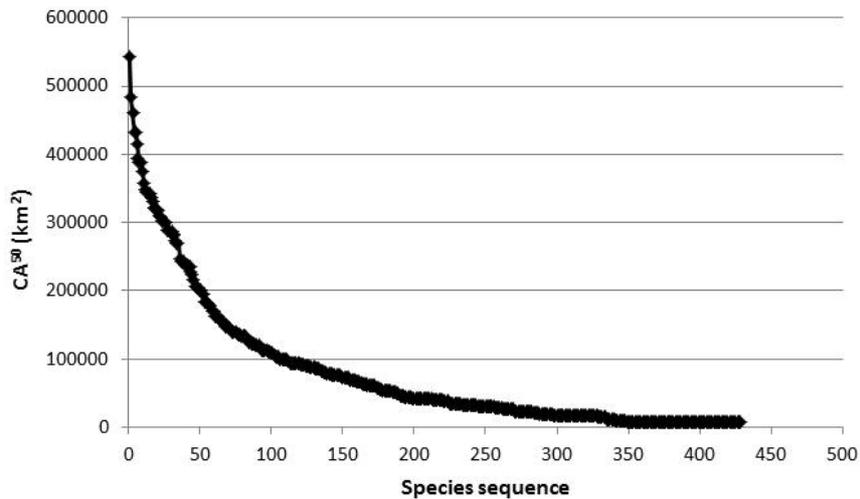


Fig. 4. Circular area CA_{50} of *Fabaceae* (except *Astragalus*) species. A circular area with a 50 km radius was assigned to each observation.

(Hijmans & Spooner 2001), Ilam, South Khorasan and Zanjan are some examples of such provinces (Table 1).

Trigonella monantha C.A. Mey. is the only species that occurs in 25 provinces, followed by *V. sativa*, *M. sativa*, *G. glabra* and *L. corniculatus* which occur in 23 provinces. The average greatest distance between two observations of the same species (MaxD) is 688 km. For 229 species, MaxD is <688 km, which indicates 53% of the total species have a MaxD lower than the average (Fig. 3). The greatest MaxD observed was for *Lathyrus aphaca* L. (2140 km). Average circular area (CA₅₀) over all species is 79618 km² and its distribution is strongly skewed (Fig. 4). More than half of the total species (68%) have a CA₅₀ less than the average.

To compare the abundance of the species in their area of distribution, we plotted the CA₅₀ to the number of observation (RCA₅₀) for each species (Fig. 5). A species with a high number of observation per CA₅₀ would be abundant within its area of distribution (or densely collected), like *Acacia oerfota* (Forssk.) Schweinf., which has the lowest RCA₅₀, whereas a low number would indicate that a species has a more scattered distribution within the range in which it occurs (or less densely collected), such as *Cercis chinensis* Bunge and *Delonix regia* (Bojer ex Hook.) Raf. which have the highest RCA₅₀ 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 indicated in Fig. 5 one species, *E. stellata* is conspicuously out of the mentioned pattern, which is because of its high observation number. For example, *E. stellata* and *Melilotus officinalis* Pall. occur in an area of comparable size (CA₅₀ = 318303 km² for *E. stellata* and 316959 km² for *M. officinalis*), but *E. stellata* has been observed about 2.5 times more often, suggesting that *E. stellata* is much more abundant (notice that comparison is between to species with different collection interest).

Since provinces have different shapes and sizes, the grid based maps showing the number of observations (Fig. 6) and species richness (Fig. 7) give much more refined 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). From north to south of Iran, areas of species richness hotspots are: (1) a broad region in the Central Alborz mountains; (2) a small area in Gilan province; (3) a large area in central east of Lorestan province; (4) an area west of Fars province (Fig. 7). Two of the total four species rich areas (areas 1 and 4) are overlapped with the areas of high observation (compare Fig. 6 and Fig. 7). Unlike the two areas

mentioned before, area 2 and 3 which are located in Gilan and Lorestan provinces respectively doesn't 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 Central Alborz, the first hotspot area for all species (Figs. 7 and 8). Also areas in Lorestan, Fars and Khorasan Razavi provinces have high number of endemic species.

Although three grid cells (located in Central Alborz, Fars and Hormozgan provinces) are enough to capture 50% of all *Fabaceae* (excluding *Astragalus*), the minimum number of grid cells needed to capture all species at least once, is forty four. Twenty first important grid cells, which contain 90% of all species, are shown in Fig. 9. The early appearance of a cell from Hormozgan province (grid cell number 3 in Fig. 10) was unexpected because it has only a low level of species richness (Fig. 7). The chart of the species accumulation for each iterative addition of a 100km² grid cell in the complementarity analysis shows that only 15 grid cell out of forty four have more than four additional species (Fig. 10).

Discussion

Here for the first time species of *Fabaceae* family in Iran (excluding *Astragalus*) are systematically analyzed, using GIS. Some of our records are recent, but many data back many years (mentioned only in available Floras). Even in some cases, the habitat in which the species occurred has now disappeared, and the species may no longer occur there. But these have not much effect on the whole results. Moreover if the observations (specimens observed) would extend to the local herbaria, such as Esfahan, FUMH, Kordestan and Tabriz, it would have great impact on the results.

The only gaps in the observation map are from central and central east of Iran which belongs to Dasht-e Kavir and Dasht-e Lut (which is one of the hottest deserts in the world). These deserts are defined as barriers for most of the taxa, these taxa progress to the borders of semi-desert and desert region and stop there (Wendelbo 1971). Moreover, the road network in this part of Iran is less than the other parts of Iran.

So it is recommended to direct some attention toward these poorly collected areas in the future. May be further exploration would discover additional species and solves the condition of nonrandom spatial distribution of species observation point (Maxted et al. 2005).

In addition recorder effort (bias) (Rich and Woodruff 1992; Gaston 1996; Hijmans et al. 2000) also influences the results. It is difficult to identify if the

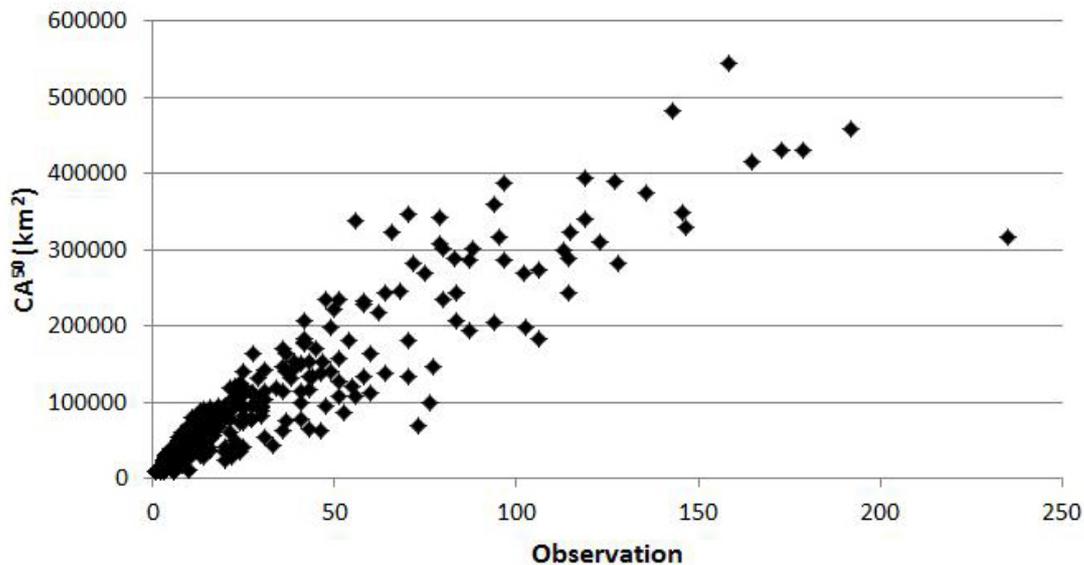


Fig. 5. Circular area (CA₅₀) vs. number of observations of *Fabaceae* (except *Astragalus*) species. Each dot refers to one species. A circular area with a 50 km radius was assigned to each observation.

species richness hotspots are truly the most species rich areas in Iran, or whether these regions have been identified as hotspots partly because they have been more completely sampled than other regions. So may be it would be assumed that, the hotspot located in Fars province is a bias, because it has the highest number of observation. But we don't think that high number of species follows casually from high number of observations.

On the contrary, hotspots located in Gilan and Lorestan provinces, which are not rich in observation. Furthermore a grid cell with 29 additional species (it has the fourth rank for additional species) in Lorestan and the high amount of rare species makes the province worthy for conservation and further investigations.

Central Alborz stands out for the high number of *Fabaceae* species as well as for the high number of endemic species. This is while in recent years strong grazing impact is increasingly threatening the fragile subalpine and alpine ecosystems in Iran, even in legally protected areas (Noroozi et al. 2008). Therefore, the protection and management of rangelands in this zone—as in all other vegetation types in Iran—needs to be considered (Noroozi et al. 2008).

Since conservation findings are limited, we preferred to use 10 × 10 km grid size to define smaller areas for conservation. The complementarity analysis lead to 44 grid cells which contain all the species, this means conserving *Fabaceae* species needs to protect only 4400 km² area which comprises about 0.27% of Iran's surface.

Since provinces have different shape and size, we used equal-area grid cells to set up distribution of the species. Using small grid sizes was to have a high resolution and either low geographic sampling bias.

A complication of using species richness is the existence of conflicting taxonomic classifications (Gaston 1996). But because we used a group of plants with a high classification rank (subfamily), further changes in species circumscription wouldn't have much effect on the results presented here.

In comparison to the high species richness Iran harbors, less systematic studies have been taken part in this country. Even germplasm collection doesn't get the sufficient attention it needs. In addition the high number of rare species (173) of *Fabaceae* (except *Astragalus*) indicates that Iran still harbors unknown species. With an aspect of the temperature increase and population growth in Iran, there is an emergency to extend exploration, conservation studies and germplasm collections.

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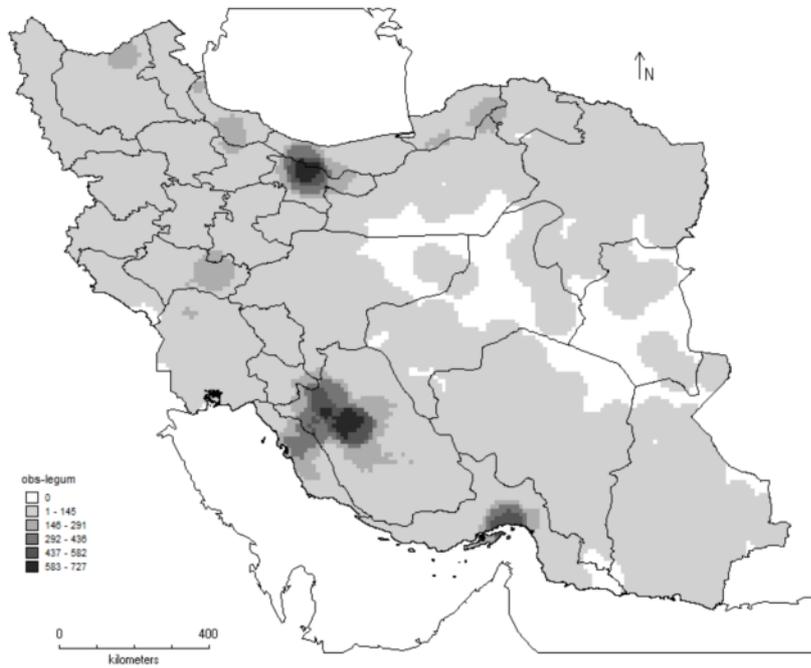


Fig. 6. Number of observations of *Fabaceae* (except *Astragalus*) species per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

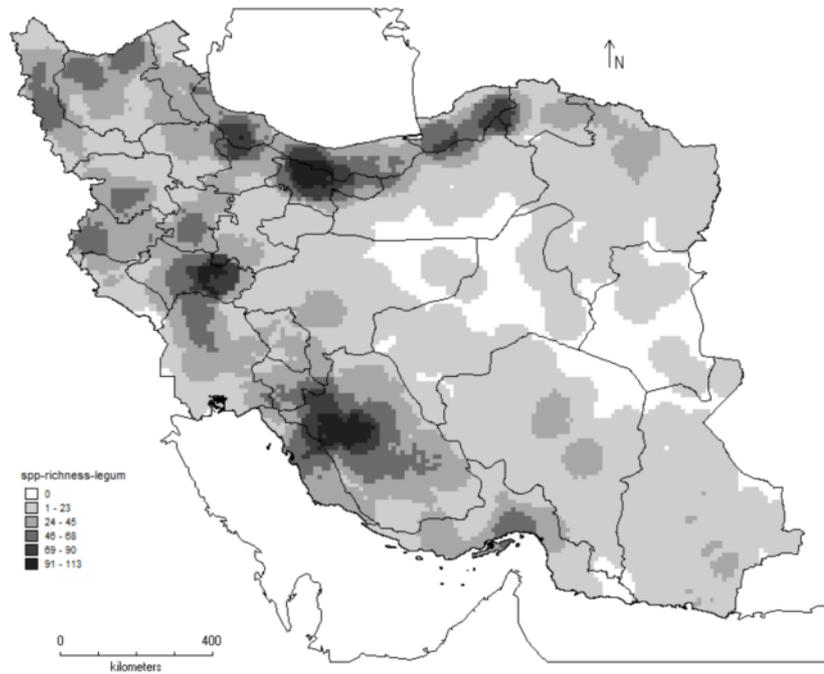


Fig. 7. Number of *Fabaceae* (except *Astragalus*) species per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

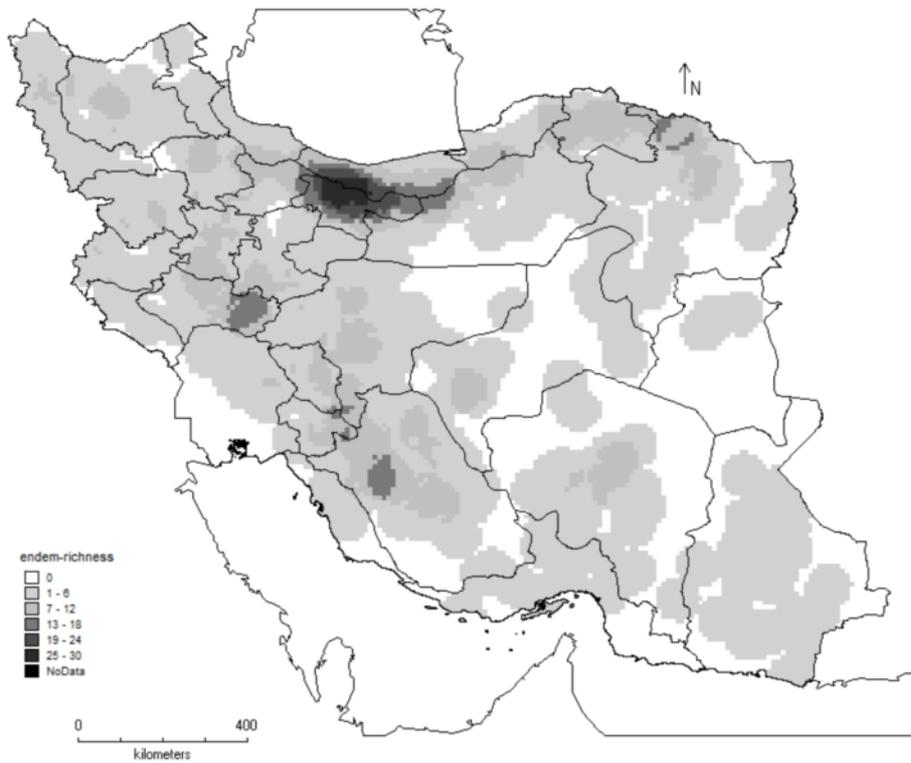


Fig. 8. Number of *Fabaceae* (except *Astragalus*) endemic species per 10×10 km grid cell. A circular neighborhood with a radius of 50 km was used to assign observations to a grid cell.

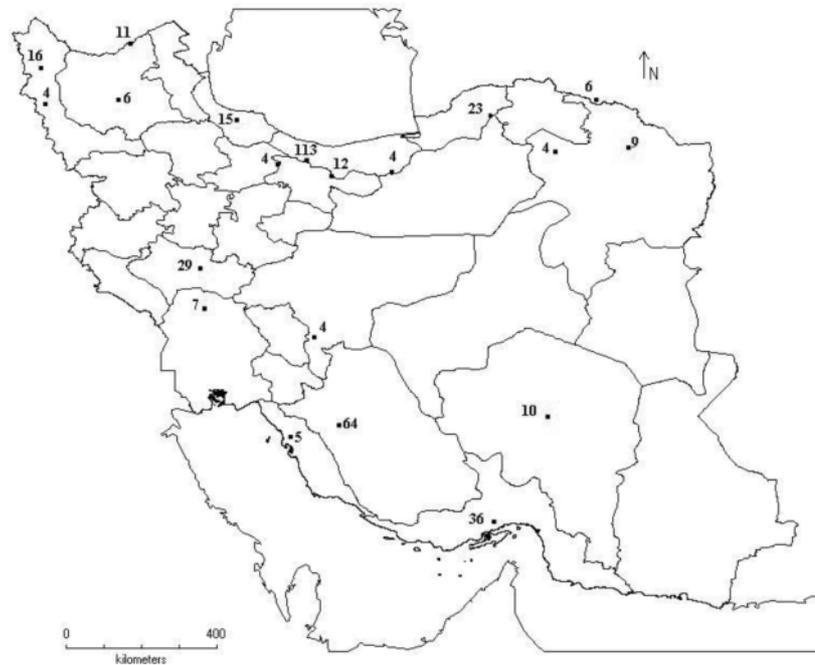


Fig. 9. The location of 20 grid cells needed to include 90% *Fabaceae* (except *Astragalus*) species.

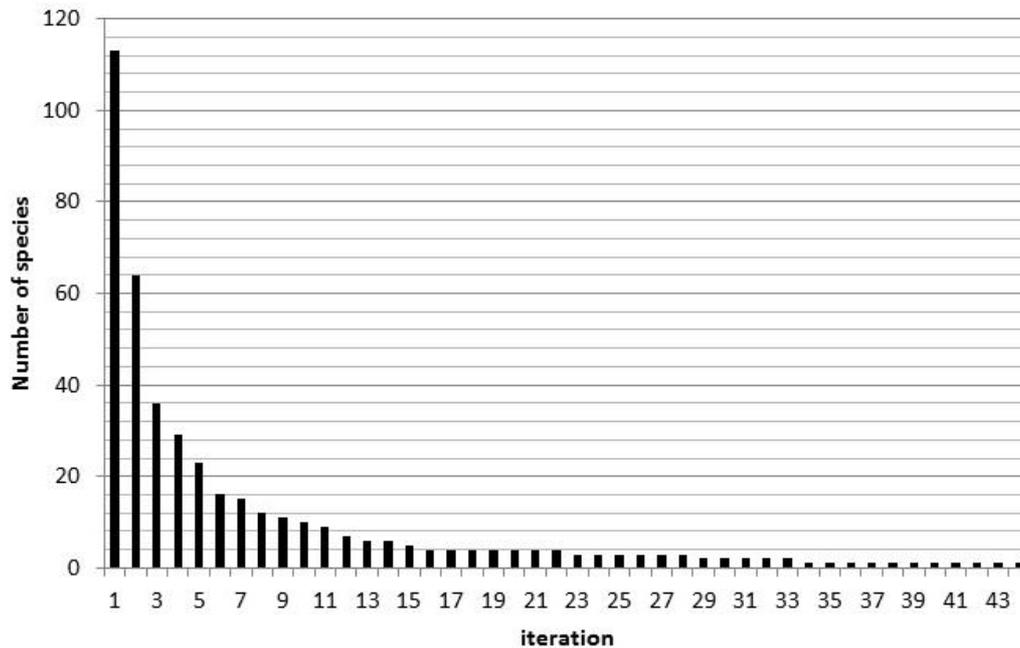


Fig. 10. Number of additional species included per grid cell, when selecting grid cells with the objective to select all species in as few grid cells as possible.

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