Modelling bryophytes distribution pattern using environmental parameters of Iran in Geographical Information Systems (GIS): a case study of three genera *Tortula*, *Grimmia* and *Bryum* (*Bryophyta*)

مدل‌سازی الگوی پراکندگی خزه‌گیان با استفاده از پارامترهای محیطی ایران در سامانه داده‌های جغرافیایی (GIS): جنس‌های مورد بررسی *Tortula*، *Grimmia* و *Bryum**

Received: 25.07.2011 / Accepted: 07.12.2011

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Abstract

In the present study, a modelling approach based on Geographical Information Systems (GIS) analysis is presented with the aim of identifying the influence of environmental parameters on three genera, namely, *Tortula*, *Grimmia* and *Bryum* as representatives of Iranian bryoflora. By using ArcGIS Desktop, we produced a model for environmental variables include altitude, precipitation, temperature and humidity. To test the model, we surveyed the effect of selected geographical and environmental variables including altitude, latitude, annual mean precipitation, maximum, minimum, and mean temperatures and humidity on distribution pathern of these three genera. Within 108 localities, 52 samples of *Bryum* (48%), 33 samples of *Grimmia* (30%) and 24 samples of *Tortula* (22%) were recorded. The digital models that we achieved revealed interesting results. Altitude map shows strong preference within three genera for mountainous regions. Almost all species limited to the regions received proper amount of average rainfall. Temperature digital map shows a negative relationship between temperature and bryophytes distribution. Modelling the four environmental parameters of Iran provides the means for a quantitative analysis of the distribution and abundance of vegetation types in every selected area, thus also allowing quantification and prediction of environmental effects on vegetation distribution. It stimulates the use of GIS in botanical investigations by putting a collection of free, relevant, high quality formatted data into the hands of botanical researchers.

Keywords: Altitude, humidity, precipitation, temperature, vegetation maps

دریافت: ۱۳۹۰/۵/۳/ پذیرش: ۱۳۹۰/۹/۱۶

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خلاصه

این بررسی با هدف تعیین اثر عوامل محیطی روی سه جنس *Tortula*، *Grimmia* و *Bryum* به عنوان نمایندگان فلور خزه‌ای ایران، مسیر مدل‌سازی را براساس واکاوی‌های سامانه اطلاعات جغرافیایی ارایه داده و با استفاده از ArcGIS Desktop مدلی را برای چهار متغیر محیطی شامل ارتفاع، بارش، درجه حرارت و رطوبت در ایران تولید کرده است. به منظور آزمایش این مدل، اثر متغیرهای محیطی و جغرافیایی شامل ارتفاع، عرض جغرافیایی، متوسط بارش سالانه، حداکثر و حداقل درجه حرارت، متوسط درجه حرارت سالانه و متوسط رطوبت سالانه روی الگوی پراکندگی سه جنس *Tortula*، *Grimmia* و *Bryum* بررسی شد. از ۱۰۸ محل جمع‌آوری، ۵۲ نمونه متعلق به جنس *Bryum* (۴۸٪)، ۳۳ نمونه متعلق به جنس *Grimmia* (۳۰٪) و ۲۴ نمونه متعلق به جنس *Tortula* (۲۲٪) گزارش شدند. مدل‌های دیجیتالی نتایج جالبی را آشکار ساختند. نقشه ارتفاعی تمایل شدید گونه‌ها را برای زیست در نواحی مرتفع نشان داد. تقریبا همه گونه‌ها محدود به نواحی هستند که مقدار مناسبی از بارش سالانه را دریافت می‌کنند. نقشه دیجیتالی درجه حرارت، رابطه منفی این متغیر را با پراکندگی خزه‌گیان نشان داد. مدل ارایه شده ابزاری برای واکاوی‌های کمی پراکندگی و فراوانی انواع پوشش‌های گیاهی در ایران را براساس چهار عامل بررسی شده فراهم می‌سازد و بنابراین، اجازه می‌دهد اثرات محیطی روی پراکندگی پوشش گیاهی را کمی ساخته و پیش‌بینی کنیم. این مدل با قرار دادن مجموعه‌ای از داده‌های کاربردی می‌تواند پایه‌ای برای پژوهشگران گیاهشناسی باشد تا با به کارگیری سامانه داده‌های جغرافیایی، در بررسی‌های گیاه‌شناسی مورد استفاده قرار گیرد.

واژه‌های کلیدی: ارتفاع، بارش، درجه حرارت، رطوبت، نقشه پوشش گیاهی

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Introduction

Species distribution is strongly influenced by geographical and environmental factors. Different elements of geographical factors such as topography and altitude or soil gradients and environmental factors such as annual mean relative humidity, annual mean temperature and annual mean precipitation have a direct or indirect influence on species distribution. This strong relationship between the presence of the organism and the environmental variables allows us to predict their distribution (Johnson 2005). Overlapping species data and digital climatic layers help us in two ways: to identify potential sites of species occurrence, and to define hotspots of richness in flora. Therefore, it is essential that a taxonomist makes a relation between these data and maps in order to illustrate the distribution and ultimately take useful decisions in conservation plans.

A powerful tool for this purpose is Geographical Information Systems (GIS). The use of GIS to model plant distribution in conservation actions has increased and diversified in recent years (Draper 2003). Patterns of bryophyte diversity and conservation value can be predicted from landscape features that are readily available from a GIS (Vanderpoorten *et al*. 2005). The role of GIS is to integrate and analyze all forms of data for assessment and monitoring purposes.

- Geographical Information Systems (GIS)

The most widely used definition of GIS is a computer-based system that captures, stores, manages, analyses and displays geographic data (Salem 2003). Records of species or habitat can be stored in a database and mapped to show where they occur. A large variety of data potentially enter into a GIS-based databank; for instance, in a biological databank, family, genus, species name, locality, date, substrate, altitude, latitude, longitude, collector(s) name, image, map of distribution etc. of each specimen can be recorded. To connect databanks to GIS software and change them to GIS-based databank, they must have a geographic property or spatial characteristic that can be mapped.

The most important ability of GIS is to analyze perplexing spatial and non-spatial data. In other words, GIS can combine and simultaneously show the spatial data, the position of species on earth, with their descriptive data. These data can be linked to geography in a number of ways through GIS; for linking process, we need to once enter specimen-related data to allow us to quickly produce maps and derive a variety of results. It can not only determine habitat biodiversity but also identify high priority places for collecting and conserving plans. The use of GIS is recommended as a more effective approach than either manual methods or non-spatial automated means, of making biodiversity assessment (Salem 2003). According to the fact that systematic and floristic works are tremendously labor-intensive and involve inordinate amounts of clerical work and other relatively unskilled labor (Bletter *et al*. 2004), today this system helps taxonomists to classify and analyze the huge amount of data accurately.

The process of changing data to maps in GIS helps to have a wider outlook on landscape and predict potential vegetation. A phenomenon exhibit spatial continuity; however, it is not always possible to sample every location. Therefore, unknown values must be estimated from data taken at specific location that can be sampled. A best definition for the estimation process in botany is predictive vegetation mapping that is predicting the geographic distribution of the vegetation composition across a landscape from mapped environmental variables (Franklin 1995). Potential vegetation maps represent a useful tool for environmental management because they synthesize different types of knowledge about the reality of the territory, which are difficult to integrate in any other way (Felicísimo *et al*. 2002). Computerized predictive vegetation mapping is made possible by the availability of digital maps of topography and other environmental variables such as soils, geology and climate variables and geographic information system software for manipulating these data (Franklin 1995). To have an accurate prediction, the first step is digitizing the raw data including sample points and environmental variables; a process that produces digital terrain model.

The "Digital Terrain Model" (DTM) is simply a statistical representation of the continuous surface of the ground by a large number of selected points with known X, Y and Z coordinates in an arbitrary coordinate field. It is also a process of mathematical modelling. In such a process, points are sampled from the terrain to be modeled with a certain observation accuracy, density and distribution; the terrain surface is then represented by the set of sample points (Li *et al*. 2005). In fact, X and Y are longitude and latitude of sample points and Z can be other attributes such as height, slope and environmental variables.

Those data that are not compiled in digital form have difficulty in four ways. First, in retrieving the metadata [i.e. the collection data and attributes of the specimen(s) associated with each point on the map], second in selecting and combining distribution datasets for various organisms, third, performing spatial statistics on the distributions and finally, overlaying species distributions onto maps of soils, climate and other environmental variables (Bletter *et al*. 2004).

GIS system is, therefore, plenty of programs that display individual points as different sizes, shapes and colors based on their relative quantitative values. One of the newest programs is ArcGIS9.3 or ArcGIS for Desktop; software that enables us to discover patterns, relationships and trends in our data that are not readily apparent in databases, spreadsheets or statistical packages. Beyond displaying our data as points on a map, ArcGIS Desktop gives us the power to manage and integrate our data, perform advanced analysis, model and automate operational processes and display our results on professional-quality maps (Esri website).

- Biological modelling

Nowadays, scientists have created complex models of species distributions using combination of map layers. This involves different geographical and environmental values such as elevation or rainfall that are built into a base map, combined with data derived by the user from other detailed knowledge about the species in question. For example, a species may be known to occur within a range of annual precipitation (pre-defined) and within a certain range of ratios between clay and sand in the soil. These together with other data can be made into a hypothetical model of the species range.

During the last two decades, using computer science substantially helps taxonomists in both accelerating the process of identifying organisms and showing their close relationship to the environment. Based on Scott *et al*. (1987) and Davis (1990), combination of data systems and geographic data could be of even greater utility, scientists tended to use geographical software in order to realize how taxa react to their environment. Scott *et al*. (1993) overlaid distribution maps for individual species in the GIS to produce maps of species richness which can be created for any group of species of biological or political interest. Jones *et al*. (1997) concluded the GIS analysis climate data to map the potential distribution of a species is a powerful method to assist germplasm collectors and managers. Flather *et al*. (1997) mapped vegetation and species distributions represent basic ecological information required in any reserve selection effort. Results of Sadler & Bradfield's survey (2000) indicate that, bryophyte specimens show unique responses in their relationships to environmental conditions with other members of these plants. According to Austin (2002) who believed: "We achieve improvements in statistical modelling based on ecological concepts"; Vanderpoorten (2002) also proved that, combining information on soil condition, land use and species distribution enabled us to predict the occurrence of species. He believed bryophyte diversity significantly correlate with forest canopy and reach a maximum in forest grid-squares including unique microhabitats hosting a rare bryoflora (Vanderpoorten 2003). Bletter *et al*. (2004) examined the correlation of a species distribution with environmental factors such as elevation or rainfall in a qualitative fashion by simultaneously displaying both the species collection points and the environmental factor map layer.

Modelling these relationships, leads taxonomists to represent species-related predictions; as Guisan *et al.* (2006) reckon practitioners need reliable predictions of species distributions to evaluate properly the impact of climate and land-use changes on the distribution, composition, structure and function of community and ecosystems. A wide variety of modelling techniques have been developed for this purpose including generalized linear models, generalized additive models, bioclimatic envelopes, habitat suitability indices and the genetic algorithm for rule-set prediction (GARP) from which Species Distribution Modelling (SDM) has become increasingly popular in recent years among researchers. Cayuela *et al*. (2009) discussed on different aspects of applications of SDM methods including quantifying the environmental niche of species, testing bio-geographical, ecological and evolutionary hypotheses, assessing species invasions, assessing the impact of climate, land use and other environmental changes on species distribution. SDM methods suggest sites of high potential of occurrence for rare unexplored species and supporting conservation planning and reserve selection. Specifically, distribution maps, accurate datasets can make it possible to formulate and test hypotheses to explain and/or predict distributions through examining layers and (more rigorously) calculating statistics on the data behind the layers which is part of spatial modelling.

Sommer *et al*. (2003) designed a useful biodiversity model: BIOM (Bio-climatic model for the extrapolation of species ranges and diversity patterns). They recommend using types of ecological data, as basic standards, gradients of temperature, precipitation and aridity, to provide principle niche dimensions and representing accessible data even in data-poor regions. On a grid-cell basis, the computer program automatically compares the habitat conditions of a certain species, as indicated by the collection sites of corresponding specimens with the abiotic conditions of all grid cells within the study-area. Other scientists introduce such models for better understanding of the relation between ecological factors and different organisms (Vargas *et al*. 2004, Felicísimo *et al*. 2002, Wohlgemuth 1998 & Chefaoui 2005).

Some global programs such as the Global Biodiversity Information Facility (GBIF), Lifemapper and national or regional efforts, such as CONABIO in Mexico, SPICA in Colombia, BioCASE in Europe and CRIA in the state of São Paulo, Brazil were designed in the world (Cayuela *et al*. 2009), but in Iran it is the first time that a digital environmental map is designed for the bryophytes.

- Why bryophytes?

Bryophytes as one of the pioneer plants play an active role in making the habitats and reaching their climax. They are also the most diverse group of land plants after the flowering plants (Mishler 2001); but due to difficulties in their identification, and lack of literature from tropical areas, they have rarely been included in biodiversity surveys (Pharo *et al*. 1997). Special importance of geographical and environmental factors on bryophytes diversity and wide range of geographical features and variable climate of Iran, demand more accurate surveys on reaction between these variables.

In spite of profitable floristic attempts to collect and identify bryophytes in Iran such as Ahmadi *et al*. (2004 & 2007), Shirzadian *et al*. (1989–2011), Frey & Kürschner (1977–2010) attempts, there is no survey on modelling the diversity of bryophytes. To reach this approach, the aims of the present research are: a) making a digital map for Iran, b) modelling the distribution pattern of three genera *Tortula*, *Grimmia* and *Bryum* in Iran using digital data, c) realizing how bryophytes are influenced by selected environmental elements, d) identifying gaps in collecting bryophytes in Iran, and e) selecting protected areas according to habitat suitability for endangered bryophytes.

Materials and Methods

- Taxa selection

In order to model plant distribution patterns, high-dispersed taxa which represent the diversity of bryophytes are included in biodiversity surveys, so three genera, *Tortula*, *Grimmia* and *Bryum* from three families *Pottiaceae*, *Grimmiaceae* and *Bryaceae*, respectively are selected as the most widespread and diverse taxa of bryophytes in Iran. They are common from northern humid habitats to arid places in the south, so they can be appropriate representative samples of bryophyte diversity in Iran.

- Data collection

To model a piece of terrain surface, first a set of data points needs to be acquired from the surface. Indeed, data acquisition is the primary (and perhaps the single most important) stage in digital terrain modelling (Li *et al*. 2005). Therefore, as first step, we investigated literatures for inclusion the previous attempts in research (Störmer 1963, Frey & Kürschner 1977, 1983 & 2010, Kürschner 1996 & 2008, Akhani & Kürschner 2004, Ahmadi *et al*. 2004). In order to get better result from field works, populated the distributions, obtained by vouchers which were collected between 1984–2011 and preserved in "IRAN" Herbarium.

After selecting some places for the occurrence of three bryophyte genera, we collected new samples during February to August 2010 and calculated the position of each locality precisely with the Global Positioning System (GPS). In order to elaborate the environmental model of above-mentioned genera, several data sets were included such as: altitude (m), latitude (º), longitude (º), annual mean precipitation (mm), maximum temperature (º C), minimum temperature (º C), mean temperature (º C) and humidity (%). The data sets of environmental variables during a five-year period (2003–2007) were obtained from Iran Meteorological Organization website.

- Databank

Species data include family, genus and species name; locality, date of collecting, substrate, altitude, latitude, longitude and collector's name, obtained from literature references, fieldwork performed during 2008–2011 and herbarium records were entered into a databank in Microsoft Office Access 2007 software (Appendix 1).

To use available data more effectively, we prepared a file in Microsoft Office Excel 2007 format include environmental data: annual mean precipitation (mm), maximum temperature (º C), minimum temperature (º C), mean temperature and humidity (%).

In some of the old attempt, because the foreign bryologists were not familiar to the localities the addresses were vague; therefore, we could not include them in the maps.

The localities of 59 species reported by Akhani & Kürschner (2004) do not have exact addresses; hence, they all had to be excluded in predicting process. In recent years, different taxonomists transfer some species to other genera; to be more up-to-date, we have recorded them with their new combinations (Appendix 2).

- GIS analysis

By using ArcGIS 10, the analog data (Microsoft Office Access and Microsoft Office Excel format) were changed to digital graphical vector data (point, line, and polygon) in shape file format. In fact, ArcGIS by "display X and Y data" option, produce vector data. "X" and "Y" are "longitude" and "latitude" in our dataset in Microsoft Office Excel format.

Different shape files must have the same coordinate system in order to conform to a model; so, after producing the shape files, we set the coordinate system for them in Arc Catalog. Interpolation in digital terrain modelling is used to determine the Z value of a point by using the known Z values of neighboring points. Interpolation techniques can be classified according to different criteria and they can be used for different purposes. One of the most commonly used techniques for interpolation of scatter points is Inverse Distance Weighted (IDW) interpolation in spatial analyst tools. At the end of this stage, we have interpolated maps for each environmental variable.

In order to make a model that gives information about the surveyed environmental variables, the raster layers convert to vector (polygon) (Figs 3–7). After that, vectorized layers were intersected two by two, and at the end, a predictive digital map for four environmental variables (altitude, temperature, humidity and precipitation) was produced. As the final step, this layer intersects with bryophytes points' layer. The final layout model has an attribute table in which Z value of each variable combine with the position of bryophytes. By using this final model, one can identify the range of each variable for distribution pattern of each genus. The summarized table is in Appendix 3. In this table, each species has been followed by their classes on each environmental variable. To know the range of each class, see the maps' legends (Figs 3–7).

Results

In the present survey, 15 provinces were covered, i.e. Tehran province with 26 and Mazandaran province with 16 bryophyte samples with respect not only to the most field trips, but also highest percentage of biodiversity in Iran (20 species of Tehran and 13 species of Mazandaran, respectively). Ardebil and Bushehr are the poorest provinces in field trips and unfortunately, there is no record for the rest of 15 provinces (Fig. 2).

Within 108 localities, 52 samples of *Bryum* (48%), 33 samples of *Grimmia* (30%) and 24 samples of *Tortula* (22%) were recorded (Fig. 1). By adding these data to the latest checklist (Akhani & Kürschner 2004), 55 species (26 *Bryum*, 13 *Tortula* and 16 *Grimmia*) were known from Iran from which *Bryum turbinatum*, *Grimmia anodon* and *G. elatior* are becoming extinct, *Bryum neodamense* is endangered, *B. schleicheri* and *B. uliginosum* are critically endangered and *G. ovalis* considered as vulnerable species (Smith 2004) while *Tortula astoma* and *T. demawendica* are endemic to Iran (Kürschner 2007) (Appendix 1).

The "IRAN" Herbarium with 66 samples of *Tortula*, *Grimmia* and *Bryum*, in comparison with published papers until now, has the most expanded field trips in bryophytes in Iran. Although, about 80% of old records are re-collected, *Bryum muehlenbeckii*, *B. pallescens*, *B. turbinatum* (extinct) and *Grimmia orbicularis* are not found yet.

According to the digital models, the distribution patterns of *Tortula* and *Grimmia* species are somehow overlapped. Altitude map shows strong preference within three genera for mountainous regions (Alborz and Zagros mountains) (Fig. 4). However, species of *Bryum* are scattered everywhere from cold coastal area (1–500 m) in the north to warm southern islands; in contrast, *Grimmia* and somehow *Tortula* are limited to mountainous regions (Figs 3 & 4). In spite of being sensitive to high temperatures, three species are found in hot southern areas (*B. weigelii*, Minoo island, *B. dichotomum*, Negin island and *T. obtusifolia* Dehkuyeh) (Fig. 5). Humidity and precipitation maps show a clear difference. The percentage of humidity does not influence bryophytes as much as the amount of rainfall does. Almost all species limited to the regions received proper amount of average rainfall (Figs 6 & 7).

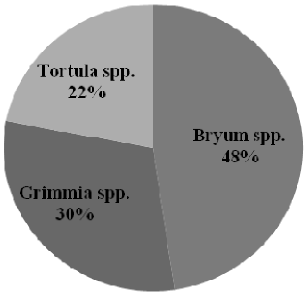

Fig. 1. Genera portions of all samples.

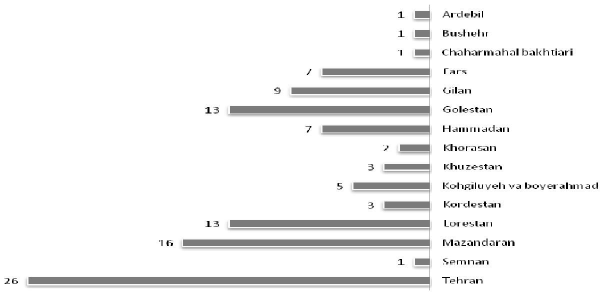

Fig. 2. Collected samples per province.

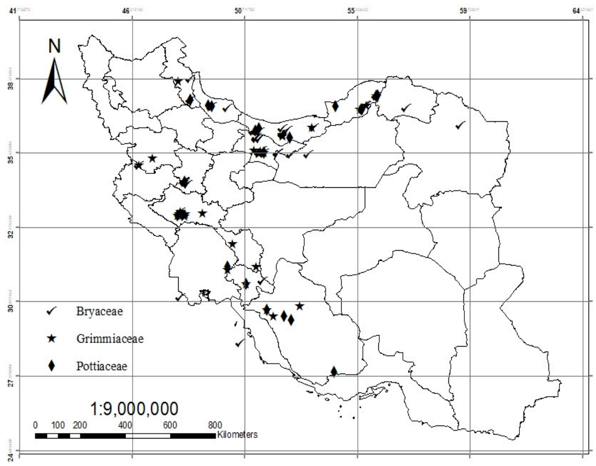

Fig. 3. Distribution of three genera.

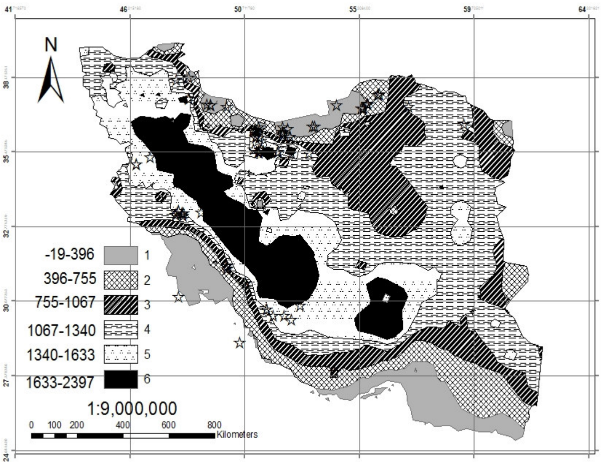

Fig. 4. Digital altitude map.

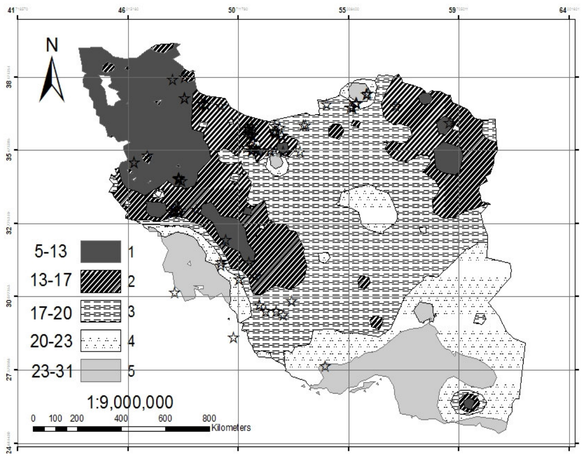

Fig. 5. Digital mean temperature map.

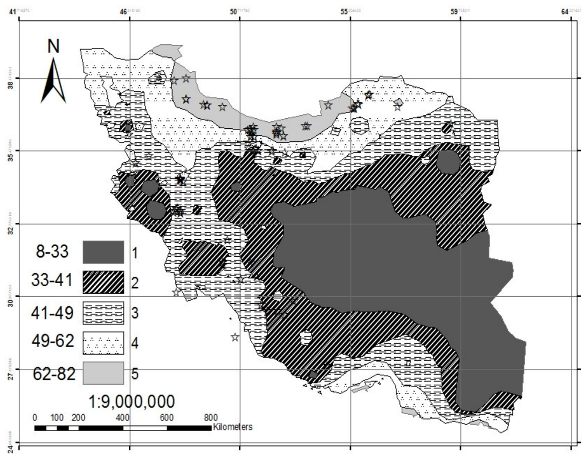

Fig. 6. Digital humidity map.

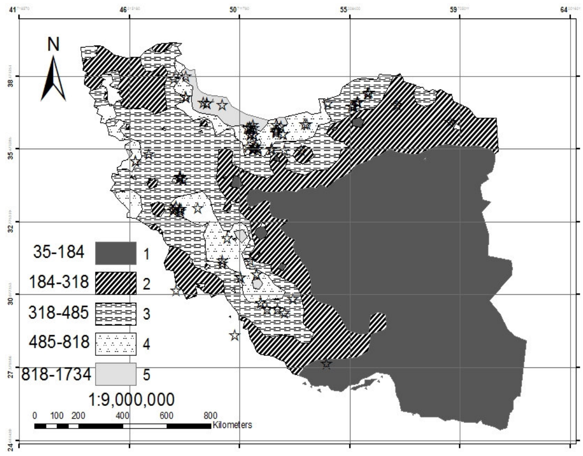

Fig 7. Digital precipitation map.

Discussion

In order to test the model, we surveyed the effect of selected environmental variables on bryophyte distribution pattern by using the attribute table of final model (Appendix 3).

At the first glance, altitude digital map shows strong preference within three genera for mountainous regions (Fig. 4). Although in Zagros mountains, they are restricted in the range between 800–2000 m, in Alborz mountains, the altitudinal range is more effective too. However, in north strip of Iran, altitude is not a limiting factor. The species are scattered from coastal lowlands (1–500 m) to mountainous regions (1000–2000 m). Our result is in agreement with Wohlgemuth (1998) in that, the altitudinal range is the most important determinant of environmental diversity and the most significant factor for explaining species distribution. Ah-peng *et al*. (2007) also showed that altitude controlled the diversity and distribution of bryophytes.

Based on the final model, species of *Bryum* are scattered in lowlands as much as highlands. Twenty six samples are found in classes of six and five and 20 samples in other classes, while these classes in *Tortula* are the most populated; 16 samples in classes of one and four versus seven samples in two high classes (Fig. 4 and Appendix 3). In contrast with *Bryum* and *Tortula*, species of *Grimmia* are limited to highlands. From 33 samples of *Grimmia*, 25 samples are scattered between classes of 6 to 4 (Fig. 4 and Appendix 3). In fact, these species are found in every mountainous region in Iran through the year, but in winters, they turn dry with black hoary cushions.

Temperature digital map shows an obvious negative relationship between temperature and bryophytes distribution (Fig. 5). Classes of five and four in temperature (20–31º C) involve three samples in *Bryum*, six samples in *Tortula* and four samples in *Grimmia* (Fig. 5 and Appendix 3). In general, almost all the species are limited in the range between 11–20º C. However, it is not reasonable that there are no records between 21–30º C which could be due to the lack of data! Taking into account that the species are abundant in the north strip; they are almost rare in Persian Gulf's coastal area, so for bryophytes, temperature is more limiting than altitude.

Based on humidity digital map and attribute table of the final model (Fig. 6 and Appendix 3), none of the genera occupies the range of 8 to 33 percentages of humidity (class 1). For instance, *Grimmia* species are more abundant in a range between 41 to 60 percentages of humidity (classes of 3 and 4) in Zagros mountainous regions. In contrast, *Bryum* species are highly affected by the levels of humidity; almost all of them need 60 to 80 percentages of humidity (classes of 3 to 5), either in the north or in the south of the country. Only two samples of *Bryum* species fall in class 2 (33–41). *Tortula* samples are equally scattered between classes 2 to 5 in humidity classes. It, therefore, seems altitude range is the only limiting factor for *Tortula* distribution.

Almost all species limited to the regions received proper amount of average rainfall. Except one species (*T. viridifolia*, class 1), the rest of them need at least 200 mm precipitation in a year and occupy classes of 2 to 5 (184–1734). Within these three genera, *Grimmia* samples are limited to classes of three and four (318–818) in the range of rainfall (Fig. 7 and Appendix 3). Samples of two other genera almost equally occupy the high classes; especially *Bryum* that have 44 samples in classes of 5 to 3 and ultimately, *Tortula* have the most records for these classes too, without any samples in the second class and one sample in the first class. Therefore, it is obvious that almost all the species are limited to classes of five to three.

Distribution of some species such as *Bryum alpinum*, *B. caespiticium*, *B. capillare*, *B. pseudotriquetrum*, *Grimmia orbicularis*, *G. laevigata*, *G. ovalis* and *Tortula muralis* is not restricted to a special climate, while *B. moravicum* and *T. caucasica* are limited to Hyrcanian forests in the north of the country and *B. pallens* and *Grimmia crinita* found only in Zagros Oak forests. This may explain their positive relationships with different forest cover (Appendix 1).

Based on the result of this study and Akhani & Kürschner's checklist (2004), there are some species recorded only from two locations. *Bryum dichotomum* surprisingly from two quite different areas: Mazandaran (Babol) and Boushehr (Negin island), *B. weigelii* from Tehran and Khuzestan, *Grimmia alpestris* from Tehran and Lorestan, *G. hartmanii* from Mazandaran and Lorestan, *G. lisae* from Tehran and Kurdestan, *Tortula demawendica* from Azarbaijan and Tehran and finally, *T. revolvens* from Kohgiluyeh-va-Boyerahmad and Golestan provinces, respectively (Appendix 1). It however suggests that, such species occupied limited fragmented areas belonging to a wide territory and have not colonized yet all its potential habitats (Vanderpoorten *et al*. 2004b), or simply we did not explore their distribution range thoroughly.

Species include *Bryum archangelicum*, *B. creberrimum*, *B. imbricatum*, *B. muehlenbeckii*, *B. rubens*, *B. subapiculatum*, *B. torquescens*, *Grimmia caespiticia*, *G. elongata*, *G. longirostris*, *G. montana*, *Tortula astoma*, *T. brevissima*, *T. canescens*, *T. obtusifolia*, *T. solmsii* and *T. viridifolia* have been recorded just once (Appendix 1). It may show either their endemism or extinction. Another explanation is inadequate works on them. *B. neodamense* is limited to the north of Tehran (Appendix 1).

Some species can be used as indicators of Zagros mountainous regions. In the present study, a subset of five species: *Bryum alpinum*, *Grimmia crinita*, *Grimmia laevigata*, *Grimmia trichophylla* and *Tortula muralis* are the most abundant species in Zagros mountains (Appendix 1). It shows the habitat suitability for *Grimmia* species in highlands of Zagros.

Unfortunately, as Ibisch *et al*. (2002) implied, floristic exploration is quite deficient and mainly restricted to areas with road access. This fact becomes more serious when we talk about areas of high endemic species diversity. These places are frequently characterized by fragmented habitat and unique climatic and edaphic conditions (Vargas 2004). This situation exist in the west of Iran where there is a big gap in field works (Fig. 2). In spite of being one of the richest regions from the viewpoint of plant species (only two endemic species in this study have been recorded from Azarbaijan province based on Akhani & Kürschner (2004), bryophytes flora of the west of Iran is partially unknown and demands further field explorations. Because of restriction of endemic species in their distribution and poor representation by herbarium specimens, it is reasonable to do further studies on provinces like Kohgiluyeh-va-Boyerahmad, Chaharmahal-o-Bakhtiari, Khorasan, Azarbaijan, Ardebil and Kermanshah instead of Tehran and Mazandaran provinces. It may help focusing the attention on sites exhibiting the appropriate landscape features for subsequent field investigation (Vanderpoorten *et al*. 2005).

Conclusion

Although altitude range is the most limiting factor for *Tortula* species, other two genera, especially *Grimmia*, are highly affected by precipitation range (Appendix 3).

Humidity and rainfall digital maps illustrate that in Iran, in spite of common belief that bryophytes are limited to the places with high precipitations and dense forests cover like northern strip of Iran, they can be found even in southern islands and dry mountainous region in central Iran; though, in the seasons the amount of rainfall is high (Figs 6 & 7). The difference is in species richness; it is obvious that species variety in northern strip is higher than central and southern regions.

This model provides the means for a quantitative analysis of the distribution and abundance of vegetation types in every selected area, thus also allowing quantification and prediction of environmental effects on vegetation distribution. It stimulates the use of GIS in botanical investigations by putting a collection of free, relevant, high quality formatted data into the hands of botanical researchers. We highly recommend using this base map and environmental model in distribution maps in the Flora of Iran series that is the central focus of efforts to document the flora of Iran completely. We strictly concur with Johnson *et al*. (2005) who implied, conservation professionals should choose a model and variable set based on the question, the ecology of the species and the availability of requisite data.

The calculation of the bryophyte species richness needs further information per each square. It is very useful tool to identify potential sites of high interest of conservation (Hespanhol *et al*. 2005). To do so, we should investigate a limited area like a protected national park or basin by a definite size of grid-squares and make the presences/absent species maps and combine it with IBM. Therefore, it is better to use GIS modelling in regional scales to get more result that is trustful from IBM. For this reason, we have to re-collect data for a specific area.

Taxonomic and morphological characteristics show some trends with respect to evaluating patterns of rarity; however, these trends differ between geographic areas. Microhabitat quantity does not determine rare species occurrence, however, the quality or uniqueness of the microhabitats may be of importance. Moss distribution patterns on a local scale reflect world distribution patterns and habitat availability (Heinlen & Vitt 2003).

To better interpret the results, statistical methods should have been used to produce potential distribution maps expressing occurrence probabilities. Considering that GIS surveys require an interdisciplinary approach, we hope that closer links between taxonomy, floristic, topography, biogeography and management may be established in the near future. This will be an essential factor in order to successfully support and design conservation programs using GIS (Draper *et al*. 2003).

However, there is always a percentage of "uncertainty" in both systematic data and measurement tools that could disappear by developing further studies. "Uncertainty" is a difficult issue, primarily because there are many different types of error and associated uncertainty. These can be measurement errors, systematic error, model error, natural variation and subjective judgment (Elith *et al.* 2002, Guisan *et al.* 2006).

We should not also ignore the important role of humans in disturbing nature. Taking into consideration that, we are unconsciously destroying our earth, bryophytes are closely linked to their habitats, must make it essential to consider the pattern of these habitats at a broader scale. Tappeiner *et al*. (1998) believe "The main factor influencing spatial variability in the vegetation in an alpine region is land-use" and Ah-peng *et al*. (2007) claimed, "Disappearance of bryophytes microhabitats means the disappearance of their affiliated biodiversity." However, it is not quite definite; for example, Vanderpoorten *et al*. (2004a) suggested that grazing, which increases the number of species (especially the number of pioneers), is likely to be more beneficial to bryophytes.

Bryophytes can survive drought and stay fresh in the months when minimum rainfall for living occurs. Based on this fact, it is highly recommended not to limit the field trips to special areas for collecting bryophytes. They may be collected everywhere under shadow rocks in the rainfall season with the proper temperature.

Acknowledgements

Authors express their special thanks to Dr. A. Mazooji and Dr. T. Nejadsattari (Islamic Azad University) for their kind cooperation during the present investigation. Special thanks are also due to Engr. M. Mokhtari (Khuzestan National Gas Company, Ahwaz) and Dr. M. Minbashi (Iranian Research Institute of Plant Protection, Tehran) for their precious work in map production and GIS analysis. We are also grateful to plant taxonomists all over the country who for years have identified specimens from Iran.

References

Ahmadi, Sh., Shirzadian, S. & Tavasoli, A. 2004. Four new species for Iran bryoflora. Rostaniha 5(1): 109–110.

Ahmadi, Sh., Shirzadian, S. & Tavasoli, A. 2007. New bryophyte species, *Anacolia webbii*, for Iran. Rostaniha 8(1): 49–51.

Ah-peng, C., Chuah-Petiot, M., Descamps-Julien, B., Bardat, J., Stamenoff, P. & Strasberg, D. 2007. Bryophyte diversity and distribution along an altitudinal gradient on a lava flow in La Réunion. Diversity and Distributions 13: 654–662.

Akhani, H. & Kürschner, H. 2004. An annotated and updated checklist of the Iranian bryoflora. Cryptogamie, Bryologie 25(4): 315–347.

Austin, M.P. 2002. Spatial prediction of species distribution: an interface between ecological theory and statistical modelling. Ecological Modelling 157: 101–118.

Bletter, N., Janovec, J., Brosi, B. & Daly, D.C. 2004. A digital base map for studying the Neotropical flora. Taxon 53(2): 469–477.

Cayuela1, L., Golicher, D.J., Newton, A.C., Kolb, M., de Alburquerque, F.S., Arets, E.J.M.M., Alkemade, J.R.M. & Pérez, A.M. 2009. Species distribution modelling in the tropics: problems, potentialities, and the role of biological data for effective species conservation. Tropical Conservation Science 2(3): 319–352.

Chefaoui, R.M., Hortal, J. & Lobo, J.M. 2005. Potential distribution modelling, niche characterization and conservation status assessment using GIS tools: a case study of Iberian *Copris* species. Biological Conservation 122: 327–338.

Davis, F.W., Stoms, D.M., Estes, J.E., Scepan, J. & Scott, J.M. 1990. An information systems approach to the preservation of biological diversity. International Journal of Geographic Information Systems 4(1): 55–78.

Draper, D., Rossello-Graell, A., Garcia, C., Tauleigne Gomes, C. & Sergio, C. 2003. Application of GIS in plant conservation programmes in Portugal. Biological Conservation 113: 337–349.

Elith, J., Burgman, M.A. & Regan, H.M. 2002. Mapping epistemic uncertainties and vague concepts in predictions of species distribution. Ecological Modelling 157: 313–329.

Esri, the GIS Software Leader/Mapping Software and Data. http://www.esri.com/software/arcgis/arcgis-for-desktop/index.html.

Felicísimo, A.M., Frances, E., Fernindez, J.M., Gonzalez-Diez, A. & Varas, J. 2002. Modelling the potential distribution of forests with a GIS. Photogrammetric Engineering & Remote Sensing 68(5): 455–461.

Flather, C.H., Wilson, K.R., Dean, D.J. & McComb, W.C. 1997. Identifying gaps in conservation networks: of indicators and uncertainty in geographic-based analyses. Ecological Applications 7(2): 531–542.

Frahm, J. 2008. Diversity, dispersal and biogeography of bryophytes (mosses). Biodiversity Conservation. 17: 277–284.

Franklin, J. 1995. Predictive vegetation mapping: geographic modelling of biospatial patterns in relation to environmental gradients. Progress in Physical Geography 19(4): 474–499.

Frey, W. & Kürschner, H. 1977. Studies on the bryophyte flora and vegetation of the Golestan National Park. Iranian Journal of Botany 1(2): 137–153.

Frey, W. & Kürschner, H. 1983a. Contributions towards a bryophyte flora of Iran, new records from Iran. Iranian Journal of Botany 2(1): 13–19.

Frey, W. & Kürschner, H. 2010. New and noteworthy records to the bryophyte flora of Iran. Nova Hedwigia 90: 503–12.

Guisan, A., Lehmann, A., Ferrier, S., Austin, M., Overton, J.MC.C. Aspinall, R. & Hastie, T. 2006. Making better biogeographical predictions of species' distributions. Journal of Applied Ecology 43: 386–392.

Heinlen, E.R. & Vitt, D.H. 2003. Patterns of rarity in mosses of the Okanogan Highlands of Washington State: an emerging coarse filter approach to rare moss conservation. The Bryologist 106(1): 34–52.

Hespanhol, H., Vieira, C., Lomba, Â. & Séneca, A. 2005. New data on bryophyte distribution in the Penedager-s National Park (NW Portugal): the use of GIS for conservation remarks. Boletin de la Sociedad Espanola de Briologia 26–27: 59–74.

Ibisch, P.L., Nowicki, C., Müller, R. & Araujo, N. 2002. Methods for the assessment of habitat and species conservation status in data-poor countries: case study of the *Pleurothallidinae* (*Orchidaceae*) of the Andean rain forests of Bolivia. Conservación de Biodiversidád en los Andes y la Amazonía 225–246.

Iran Meteorological Organization website: http://www.irimo.ir/farsi/publication/index.asp.

Johnson, C.J. & Gillingham, M.P. 2005. An evaluation of mapped species distribution models used for conservation planning. Environmental Conservation 32(2): 1–12.

Jones, P.G., Beebe, S. E., Tohme, J. & Galwey, N.W. 1997. The use of geographical information systems in biodiversity exploration and conservation. Biodiversity and Conservation 6: 947–958.

Kürschner, H. 1996. Towards a bryophyte flora of the Near- and Middle East. New records from Iran, Jordan, Kuwait, Lebanon, Oman, Saudi Arabia, Syria, and Turkey. Nova Hedwigia 63(1–2): 261–271.

Kürschner, H. 1997. An annotated, corrected, and updated list of the bryological literature of Southwest Asia. Cryptogamie, Bryologie-Lichenologie 18: 1–46.

Kürschner, H. 2006. A key to the pleurocarpous mosses (*Bryophytina* p.p.) of the Near- and Middle East. Towards a bryophyte flora of the Near- and Middle East, 5. Nova Hedwigia 83: 353–386.

Kürschner, H. 2007. A key to the *Pottiaceae* (*Bryopsida-Bryophytina*) of the Near- and Middle East. Towards a bryophyte flora of the Near- and Middle East, 6. Nova Hedwigia 84: 21–50.

Kürschner, H. 2008. A key to the acrocarpous mosses (*Bryophytina* p.p., excl. *Pottiaceae*) of the Near- and Middle East. Towards a bryophyte flora of the Near- and Middle East, 7. Nova Hedwigia 86: 43–103.

Kürschner, H., Papp, B. & Akhani, H. 2000. New records to the bryophytes flora of Iran studies on the flora and vegetation of the Golestan National Park, NE Iran IV. Nova Hedwigia 71(3–4): 509–518.

Li, Z., Zhu, Q. & Gold, C. 2005. Digital Terrain Modelling: Principles and Methodology. CRC Press, New York.

Mishler, B.D. 2001. The biology of bryophytes. American Journal of Botany 88: 2129–2131.

Pharo, E.J. & Beattie, A.J. 1997. Bryophyte and lichen diversity: a comparative study. Australian Journal of Ecology 22: 151–162.

Sadler, K.D. & Bradfield, G.E. 2000. Micro-scale distribution patterns of terrestrial bryophytes in a subalpine forest: the use of logistic regression as an interpretive tool. Community Ecology 1(1): 57–64.

Salem, B.B. 2003. Application of GIS to biodiversity monitoring. Journal of Arid Environments 54: 91–114.

Scott, J.M., Csuti, B., Joacobi, J.D. & Estes, J.E. 1987. A geographic approach to protecting future biological diversity. Bioscience 37(11): 782–788.

Scott, J.M., Davis, F., Csuti, B., Noss, R., Butterfield, G.C., Anderson, H. Caccio, S., D'Erchia, F., Edwards, T.C., Ulliman, J. & Wright, R.G. 1993. Gap analysis: a geographic approach to conservation of biological diversity. Wildlife Monographs 123: 1–41.

Shirzadian, S. 1989. Additions to the moss flora of Iran. Yushania 6(4): 17–20.

Shirzadian, S. 1993. Systematic study of some Iranian mosses. PhD Thesis, Panjab University, Chandigarh, India. 220 pp. 71 pls. (unpublished).

Shirzadian, S. 1994. Systematic study of some Iranian mosses. PhD Thesis Abstract. Research Bulletin of the Panjab University.

Shirzadian, S. & Kumar, S.S. 1994. A report on the moss flora of northern Iran. Iranian Journal of Botany 6(2): 177–184.

Smith, A.J.E. 2004. The Moss Flora of Britain and Ireland. Cambridge University Press.

Sommer, J.H., Nowicki, C., Rios, L., Barthlott, W. & Ibisch, P.L. 2003. Extrapolating species ranges and biodiversity in data-poor countries: The computerized model BIOM. Revista de la Sociedad Boliviana de Botánica 4(1): 171–190.

Störmer, P. 1963. Iranian plants collected by P. Wendelbo in 1959. VI. Mosses (*Musci*). Universitatis Bergensis Ârbok Mathematica Rerumque Naturalium Series 11: 1–34.

Tappeiner, U., Tasser, E. & Tappeiner, G. 1998. Modelling vegetation patterns using natural and anthropogenic influence factors: preliminary experience with a GIS based model applied to an Alpine area. Ecological Modelling 113: 225–237.

Vanderpoorten, A. & Engels, P. 2002. The effects of environmental variation on bryophytes at a regional scale. Ecography 25: 513–522.

Vanderpoorten, A. & Engels, P. 2003. Patterns of bryophyte diversity and rarity at a regional scale. Biodiversity and Conservation 12: 545–553.

Vanderpoorten, A., Delescaille, L. & Jacquemart, A.L. 2004a. The bryophyte layer in a calcareous grassland after a decade of contrasting mowing regimes. Biological Conservation 117: 11–18.

Vanderpoorten, A., Engels, P. & Sotiaux, A. 2004b. Trends in diversity and abundance of obligate epiphytic bryophytes in a highly managed landscape. Ecography 27: 567–576.

Vanderpoorten, A., Sotiaux, A. & Engels, P. 2005. A GIS-based survey for the conservation of bryophytes at the landscape scale. Biological Conservation 121: 189–194.

Vargas, J.H., Consiglio, T., Jørgensen, P.M. & Croat, T.B. 2004. Modelling distribution patterns in a species-rich plant genus, *Anthurium* (*Araceae*), in Ecuador. Diversity and Distributions 10: 211–216.

Wohlgemuth, T. 1998. Modelling floristic species richness on a regional scale: a case study in Switzerland. Biodiversity and Conservation 7: 159–177.

Appendix 1. List of species with the localities

Species	Locality
Bryum alpinum Huds.	Hamadan: Alvand Mts.
B. alpinum Huds.	Khorasan N.: SW of Bojnourd, Salook (Pr.)
B. alpinum Huds.	Lorestan: Khorram Abad, Sarmargh
B. alpinum Huds. var. *viride* Husn.	Mazandaran: Alborz Mts., Kelardasht
B. argenteum Hedw.	Golestan: Golestan National Park (Pr.)
B. argenteum Hedw.	Hamadan: Darreh-e Morad Beig
B. argenteum Hedw.	Mazandaran: Haraz valley, Karehsang,
B. argenteum Hedw.	Tehran: Alborz Mts., near Pasqaleh in the valley above Darband
B. argenteum Hedw. var. *lanatum* (B. Beauv.) Hampe	Mazandaran: Alborz Mts., Kelardasht, south of Rudbarak
B. caespiticium Hedw.	Gilan: Asalem to Khalkhal
B. caespiticium Hedw.	Golestan: Golestan National Park (Pr.)
B. caespiticium Hedw.	Mazandaran: Babol, Galougah forest, Niala
B. caespiticium Hedw.	Tehran: Alborz Mts., near Pasqaleh in the valley above Darband
B. caespiticium Hedw.	Tehran: Asara
B. caespiticium Hedw.	Tehran: Damavand, near Pulur
B. caespiticium Hedw.	Tehran: Shemshak, Dizin
B. caespiticium Hedw. var. *badium* Bruch ex Brid.	Khorasan: Hezar Masjed, Marshak to Cheshmeh-e Kabkan
B. caespiticium Hedw. var. *comense* (Schimp.) Husn.	Lorestan: Shemacha, Mt. Kellal
B. capillare Hedw.	Gilan: Rasht
B. capillare Hedw.	Gilan: Rasht to Sangar

Appendix 1. (contd.)

B. capillare Hedw.	Golestan: Golestan National Park (Pr.)
B. capillare Hedw.	Hamadan: Imam Zadeh Kuh
B. capillare Hedw.	Mazandaran: Chalus, Marzan Abad
B. capillare Hedw.	Tehran: Lavasan
B. capillare Hedw.	Tehran: Shemshak, Dizin
B. capillare Hedw. var. *flaccidum*	Tehran: Nezva kuh area, south and above Tarud
B. capillare Hedw. var. *torquescens*	Mazandaran: Haraz valley, near Mangol
B. creberrimum Taylor	Tehran: Asara
B. dichotomum Hedw.	Boushehr: Negin (Alafdoun) Island
B. dichotomum Hedw.	Mazandaran: Babol
B. imbricatum (Schwägr.) Bruch & Schimp.	Tehran: Shemshak, Dizin
B. moravicum Podp.	Mazandaran: Nowshahr, Srijamand
B. muehlenbeckii Bruch & Schimp.	Kordestan: Pass about 100 km to Kermanshah on the road to Sanandaj
B. neodamense Itzigs. ex Müll. Hal.	Tehran: Northern end of Kandevan tunnel
B. neodamense Itzigs. ex Müll. Hal. +	Tehran: Fasham, Abnik
B. pallens Sw.	Kohgiluyeh-va-Boyerahmad: Sisakht, Darreh-e Andersa, Cheshmeh mishi
B. pallescens Schleich.	Golestan: Golestan National Park (Pr.)
B. pallescens Schleich.	Tehran: Alborz Mts., near Pasqaleh in the valley above Darband
B. pseudotriquetrum (Hedw.) Gaertn., Meyer & Scherb.	Gilan: Lavandevil to Astara, Kutah Kumeh hot water spring
B. pseudotriquetrum (Hedw.) Gaertn., Meyer & Scherb.	Tehran: Damavand, near Imam Zadeh Hashem
B. rubens Mitt.	Mazandaran: Alborz Mts., 2 km from Mahmudabad towards Babolsar
B. schleicheri DC. +	Hamadan: Meydan-e Mishan, Takht-e Nader
B. subapiculatum Hampe	Tehran: Lavasan
B. turbinatum (Hedw.) Turner	Semnan: Nezva kuh area, Bashm (Shahmirzad) kuh
B. uliginosum (Brid.) Bruch & Schimp.	Mazandaran: Chalus, Marzan Abad
B. uliginosum (Brid.) Bruch & Schimp.	Tehran: Lavasan
B. uliginosum (Brid.) Bruch & Schimp. +	Gilan: Lahijan, tea farm
B. weigelii Spreng.	Khouzestan: Minoo Island
B. weigelii Spreng.	Tehran: Fasham, Abnik
Bryum sp.	Lorestan: Khorram Abad, Varak waterfall
Bryum sp.	Hamadan: Imam Zadeh Kuh
Bryum sp.	Kohgiluyeh-va-Boyerahmad: Sisakht, Koh gol, Tang-e namak waterfall
Grimmia alpestris (Web. & Mohr) Schleich.	Lorestan: Khorram Abad, Varak waterfall
G. crassifolia Lindb.	Lorestan: Khoram Abad, Sefidkuh, Shoa
G. crassifolia Lindb.	Tehran: Niyavaran
G. crinita Brid.	Fars: Ghaemiyeh, Cheshmeh-e Imam Zadeh Seyyed Hossein, the mountain opposite the pool
G. crinita Brid.	Fars: Shiraz to Kazeroun
G. crinita Brid.	Lorestan: Mamoulan, Sarfarash
G. elatior Bruch ex Bals.-Criv. & De Not.	Lorestan: Khorram Abad, Reza Abad
G. elatior Bruch ex Bals.-Criv. & De Not. +	Khouzestan: Seydon to Baghmalek, waterfall near road
G. elongata Kaulf.	Tehran: Fasham, Zardband, Meygoon
G. hartmanii Schimp.	Lorestan: Khorram Abad, Kamalvand
G. laevigata (Brid.) Brid.	Ardebil: Sarein, Girip-pola
G. laevigata (Brid.) Brid.	Fars: Shahr-e Parsi (Takht-e Jamshid)
G. laevigata (Brid.) Brid.	Kohgiluyeh-va-Boyerahmad: Dehdasht, Choram
G. laevigata (Brid.) Brid.	Tehran: Alborz Mts., near Pasqaleh in the valley above Darband
G. laevigata (Brid.) Brid.	Tehran: Niyavaran
G. lisae De Not.	Kordestan: between Kermanshah and Rezayeh, ca. 25 km behind Sanandaj in direction Saqqez
G. lisae De Not.	Tehran: 40 km after Karadj to Chalus
G. longirostris Hook.	Hamadan; Ganj nameh waterfall
G. montana Bruch & Schimp.	Tehran: Lavasan
G. orbicularis Bruch ex Wilson	Golestan: Golestan National Park (Pr.)
G. orbicularis Bruch ex Wilson var. *persica* Schiffn.	Kordestan: Pass about 100 km N of Kermanshah on the road to Sanandaj

Appendix 1. (contd.)

G. ovalis (Hedw.) Lindb.	Lorestan: Khorram Abad, Kamalvand
G. ovalis (Hedw.) Lindb.	Mazandaran: Behshahr, Mahdirajeh
G. ovalis (Hedw.) Lindb.	Tehran: Alborz Mts., near Pasqaleh in the valley above Darband
G. pulvinata (Hedw.) Sm.	Golestan: Golestan National Park (Pr.)
G. pulvinata (Hedw.) Sm.	Lorestan: Dorod, Ti
G. pulvinata (Hedw.) Sm.	Lorestan: Khorram Abad, Kamalvand
G. pulvinata (Hedw.) Sm.	Mazandaran: Haraz valley, above Siah Bisheh
G. trichophylla Grev.	Chahrmahal-e Bakhtiari: Baraftab
G. trichophylla Grev.	Kohgiluyeh-va-Boyerahmad: Basht
G. trichophylla Grev.	Lorestan: Khorram Abad, Sarmargh
Grimmia sp.	Golestan: Golestan National Park (Pr.)
Tortula atrovirens (Sm.) Lindb.	Khouzestan: Baghmalek, Ghaletol, Mal Agha
T. caucasica Lindb. ex Broth.	Golestan: Alborz Mts., between Azadshahr (Shahpasand) and Gorgan
T. caucasica Lindb. ex Broth.	Mazandaran: Alborz Mts., near Kelardasht
T. mucronifolia Schwägr.	Golestan: Golestan National Park (Pr.)
T. mucronifolia Schwägr.	Golestan: Golestan National Park (Pr.)
T. mucronifolia Schwägr.	Tehran: Lavasan
T. muralis Hedw.	Fars: Ghaemiyeh, Cheshmeh-e Imam Zadeh Seyyed Hossein, the mountain opposite the pool
T. muralis Hedw.	Fars: Shiraz, Kohmareh Sorkhi
T. muralis Hedw.	Fars: Shiraz, Sabzpushan
T. muralis Hedw.	Gilan: 12 km west of Ramsar
T. muralis Hedw.	Gilan: Rasht
T. muralis Hedw.	Golestan: Golestan National Park (Pr.)
T. muralis Hedw.	Kohgiluyeh-va-Boyerahmad: Dehdasht, Choram, Cheshmeh Belgheys
T. muralis Hedw.	Lorestan: Mamoulan, Sarfarash
T. muralis Hedw. var. *aestiva* Hedw.	Mazandaran: Polsefid, Alasht
T. muralis Hedw. var. *aestiva* Hedw.	Mazandaran: Chalus
T. muralis Hedw. var. *muralis*	Mazandaran: Polsefid, Alasht
T. obtusifolia (Schwägr.) Math.	Fars: Dehkuyeh
T. revolvens (Schimp.) G. Roth. var. *obtusata* Reimers	Golestan: Ghare-gheer rangeland, S. of Ala-gol lake
T. solmsii (Schimp.) Limpr.	Hamadan: Darreh Morad Beig
T. subulata Hedw.	Tehran: Lavasan
T. subulata Hedw.	Gilan: Asalem forest
T. subulata Hedw. var. *angustata* (Schimp.) Limp. in Rab.	Gilan: Asalem to Khalkhal
T. viridifolia (Mitt.) Blockeel & A.J.E. Smith	Golestan: Alborz Mts., 10 km south of Shahpasand

+ Endangered species based on Smith 4002.

Appendix 2. Synonym species

Species	References and remarks
B. caespiticium Hedw. var. *badium* Bruch ex Brid.	"IRAN" Herbarium [Syn.: *B. badium* (Brid.) Schimp.]
B. caespiticium Hedw. var. *comense* (Schimp.) Husn.	Kürschner 1996 (Syn.: *B. comense* Schimp.)
B. creberrimum Taylor	"IRAN" Herbarium (Syn.: *B. affine* Lindb. & Arnell, *B. lisae* De Not.)
B. imbricatum (Schwägr.) Bruch & Schimp.	"IRAN" Herbarium [Syn.: *B. amblyodon* Müll. Hal., *B. inclinatum* (Brid.) Blandow, *B. stenotrichum* Müll. Hal.]
B. moravicum Podp.	"IRAN" Herbarium (Syn.: *B. flaccidum* auct., *B. laevifilum* Syed, *B. subelegans* Kindb.)
B. subapiculatum Hampe	"IRAN" Herbarium (Syn.: *B. atrovirens* Brid., *B. erythrocarpum* Schwägr.)
T. caucasica Lindb. ex Broth.	Kürschner 2010 [Syn.: *Pottia intermedia* (Turner) Fürnr., *T. modica* R.H. Zander]
T. caucasica Lindb. ex Broth.	Kürschner 2010 [Syn.: *P. intermedia* (Turner) Fürnr., *T. modica* R.H. Zander]

Appendix 3. Atribute table based on final model

Species	Humidity class	Temperature class	Altitude class	Precipitation class
Bryum alpinum Huds.	3	2	5	4
B. alpinum Huds.	3	1	6	3
B. alpinum Huds.	4	2	4	2
B. alpinum Huds. var. *viride* Husn.	5	2	3	5
B. argenteum Hedw.	4	1	6	3
B. argenteum Hedw.	3	3	5	3
B. argenteum Hedw.	5	3	1	4
B. argenteum Hedw.	4	4	2	3
B. argenteum Hedw. var. *lanatum* (B. Beauv.) Hampe	5	1	4	4
B. caespiticium Hedw.	3	3	5	3
B. caespiticium Hedw.	3	2	5	3
B. caespiticium Hedw.	4	1	5	4
B. caespiticium Hedw.	4	1	5	4
B. caespiticium Hedw.	5	3	1	4
B. caespiticium Hedw.	5	3	1	3
B. caespiticium Hedw.	5	1	5	4
B. caespiticium Hedw. var. *badium* Bruch ex Brid.	3	1	4	2
B. capillare Hedw.	3	1	6	3
B. capillare Hedw.	3	1	6	4
B. capillare Hedw.	4	1	5	4
B. capillare Hedw.	5	2	1	5
B. capillare Hedw.	5	2	1	5
B. capillare Hedw.	4	5	2	3
B. capillare Hedw. var. *flaccidum*	4	1	6	3
B. capillare Hedw. var. *torquescens*	5	3	1	4
B. creberrimum Taylor	4	1	5	4
B. dichotomum Hedw.	5	3	1	4
B. imbricatum (Schwägr.) Bruch & Schimp.	4	1	5	4
B. moravicum Podp.	5	2	3	5
B. muehlenbeckii Bruch & Schimp.	3	1	5	4
B. neodamense Itzigs. ex Müll. Hal.	3	2	5	3
B. neodamense Itzigs. ex Müll. Hal.	4	1	6	4
B. pallens Sw.	2	2	6	4
B. pallescens Schleich.	3	3	5	3
B. pallescens Schleich.	4	4	2	3
B. pseudotriquetrum (Hedw.) Gaertn., Meyer & Scherb.	3	3	5	3
B. pseudotriquetrum (Hedw.) Gaertn., Meyer & Scherb.	5	2	1	5
B. rubens Mitt.	5	3	1	4
B. schleicheri DC.	4	1	6	3
B. subapiculatum Hampe	3	1	6	4
B. turbinatum (Hedw.) Turner	3	3	4	2
B. uliginosum (Brid.) Bruch & Schimp.	5	2	2	5
B. uliginosum (Brid.) Bruch & Schimp.	5	1	4	4
B. weigelii Spreng.	3	2	5	3
Bryum sp.	3	2	4	4
Bryum sp.	2	2	6	4
Bryum sp.	3	1	6	3
Grimmia alpestris (Web. & Mohr) Schleich.	3	2	4	4
G. crassifolia Lindb.	3	2	4	4
G. crassifolia Lindb.	2	3	5	3
G. crinita Brid.	2	3	5	3
G. crinita Brid.	3	3	4	3
G. crinita Brid.	3	2	4	4
G. elatior Bruch ex Bals.-Criv. & De Not.	2	4	3	3
G. elatior Bruch ex Bals.-Criv. & De Not.	3	2	4	4
G. elongata Kaulf.	3	2	5	3
G. hartmanii Schimp.	3	2	4	4
G. laevigata (Brid.) Brid.	2	3	5	3
G. laevigata (Brid.) Brid.	3	4	3	3

Appendix 3 (contd.)

G. laevigata (Brid.) Brid.	2	3	5	3
G. laevigata (Brid.) Brid.	3	3	5	3
G. laevigata (Brid.) Brid.	5	1	4	3
G. lisae De Not.	3	2	5	3
G. lisae De Not.	3	3	5	4
G. longirostris Hook.	4	1	6	3
G. montana Bruch & Schimp.	3	1	6	4
G. orbicularis Bruch ex Wilson	4	5	2	3
G. orbicularis Bruch ex Wilson var. *persica* Schiffn.	3	1	5	4
G. ovalis (Hedw.) Lindb.	3	2	4	4
G. ovalis (Hedw.) Lindb.	3	3	5	3
G. ovalis (Hedw.) Lindb.	5	3	1	4
G. pulvinata (Hedw.) Sm.	3	2	4	4
G. pulvinata (Hedw.) Sm.	2	2	5	4
G. pulvinata (Hedw.) Sm.	5	3	1	4
G. pulvinata (Hedw.) Sm.	5	3	1	4
G. pulvinata (Hedw.) Sm.	5	3	1	3
G. trichophylla Grev.	2	1	6	3
G. trichophylla Grev.	3	1	6	4
G. trichophylla Grev.	3	2	5	4
Grimmia sp.	4	4	2	3
Tortula atrovirens (Sm.) Lindb.	2	4	3	4
T. caucasica Lindb. ex Broth.	5	2	3	5
T. caucasica Lindb. ex Broth.	4	5	2	3
T. mucronifolia Schwägr.	3	1	6	4
T. mucronifolia Schwägr.	4	3	1	3
T. mucronifolia Schwägr.	4	5	2	3
T. muralis Hedw.	2	3	5	3
T. muralis Hedw.	2	3	5	3
T. muralis Hedw.	3	3	4	3
T. muralis Hedw.	3	4	3	3
T. muralis Hedw.	3	2	4	4
T. muralis Hedw.	5	3	1	3
T. muralis Hedw.	5	2	1	5
T. muralis Hedw.	5	2	1	5
T. muralis Hedw. var. *aestiva* Hedw.	5	3	1	4
T. muralis Hedw. var. *aestiva* Hedw.	5	2	1	5
T. muralis Hedw. var. *muralis*	5	3	1	4
T. obtusifolia (Schwägr.) Math.	2	5	3	1
T. revolvens (Schimp.) G. Roth. var. *obtusata* Reimers	5	3	1	3
T. solmsii (Schimp.) Limpr.	4	1	6	3
T. subulata Hedw.	3	1	6	4
T. subulata Hedw.	5	1	5	4
T. subulata Hedw. var. *angustata* (Schimp.) Limp. in Rab.	5	1	5	4
T. viridifolia (Mitt.) Blockeel & A.J.E. Smith	4	5	2	3