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Title: Areas of endemism and threatened flora in a Mediterranean hotspot: Southern Spain

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Abstract A new methodology combining the concepts of endemicity and threat in order to provide an objective and highly accurate selection of protected areas is defined. This is a new method to recognize areas of endemism which combines the results yielded by NDM program, based on the optimality criterion, and those obtained using MARXAN software, designed to ensure the representation of species in the management of biodiversity. The method has been tested using the endemic and threatened vascular flora of the South of the Iberian Peninsula (Andalusia). Eleven areas of endemism have been identified in this territory; Sierra Nevada, Sierra Bermeja and Sierra Tejeda y Almijara stand out primarily. Although most of the areas dealt with in our study are already efficiently protected, the intermountain depression known as the Hoya de Baza, an arid area, and Sierra de Gádor are exceptions. This new methodology provided a useful tool in the fine-tuning of the selection of areas of endemism. A more precise and flexible selection of scale-dependent endemicity areas was accomplished in this manner. The combination of both criteria (endemicity and threat) not only provides a reliable representation of areas of endemism, but also optimum efficiency in terms of endemicity and presence threatened of species. This approach offers a more objective and flexible strategy which can be implemented on different scales. A lot of alternatives can be generated, so the same conservation objective can be achieved by different combinations of solutions. This is a great advantage for the prioritization of territories meriting conservation.

Areas of endemism and threatened flora in a Mediterranean hotspot: Southern Spain.

Keywords Endangered flora. Endemic flora. Biodiversity loss. Biogeography. Conservation. Mediterranean Basin.

Introduction

Both the knowledge of the distribution patterns of endemic species and the identification of the centres of endemism are essential not only for studies on historical biogeography but also for the determination of protected areas (Humphries et al. 1995; Pérez-García et al. 2012; Szumik et al. 2002).

Usually, the distribution area of a species is well defined. However, a species can be considered as "endemic", depending on the plotting of the limits of the study area. For this reason, some authors have argued that endemicity is a relative concept (Favarger and Contandrionopoulos 1961; Mota et al. 2003).

The concept of area of endemism has been widely debated in biogeography. Richardson (1978) pointed that endemic species do not take place by chance; they tend to be concentrated heavily in specific places. On the other hand, the determination of areas of endemism has several problems. Biogeographical patterns are masked by many other factors, either past or present, related to the dispersal, extinction, etc. of species; or by bioclimatic variables (Cañadas et al. 2014; Carvalho et al. 2011; Harold and Mooi 1994; Linder 2001). A definition of area of endemism is either an area where species which take place nowhere else can be found, or where numerous species are endemic, or areas of non-random distributional congruence among different taxa (Morrone 1994).

Endemic species have been recognized as a reliable subrogate of biodiversity (Domínguez et al. 2006; Lamoreaux et al. 2006). On account of the interest that endemic species have aroused among researchers and naturalists, there is much more information on them than on other widely distributed taxa (Blanca and Valle 1986). Given the restricted character of the distribution areas involved, endemic species have been included in red lists in their different threat categories (IUCN 2001). As is well known, biodiversity is declining at an alarming rate (Leakey and Lewin 1996; May et al. 1995; Mendoza-Fernández et al. 2014a, 2014b; Pimm et al. 1995). This has encouraged the development of scientific disciplines aimed at understanding and assessing the "mechanisms" ruling the patterns of biological diversity. One of these disciplines, Conservation Biogeography, has become a key tool for the interpretation of the spatial distribution of biodiversity and the promotion of more efficient conservation strategies (Grehan 1993; Lodle and Whittaker 2011; Schmeller et al. 2014; Whittaker et al. 2005).

The combination of the parameters species richness, species rarity, endemic species richness and threat category of taxa has been used as the basis for one of the most widely used approach to the biodiversity assessment (Alonso-Redondo et al. 2013; Myers et al. 2000; Schatz et al. 2014). However, it has been questioned whether the various approaches are always coherent (Orme et al. 2005; Possingham and Wilson 2005).

The main aim of this paper is to define a new methodology for the determination of the areas of endemism as a useful tool for the selection of protected areas. For this purpose, we have calculated the degree of spatial co-occurrence of two fundamental criteria in the estimation of biodiversity, namely, areas of endemism and threat category of taxa. These criteria help determine whether a territory should be considered a centre of endemicity. The analysis involved the implementation of two software programs based on different approaches. NDM/VNDM v.3 software (Goloboff 2004; Szumik et al. 2002; Szumik and Goloboff 2004) was used to determine the areas of endemism, and MARXAN v.2.11 software (Ball et al. 2009; Possingham et al. 2000; Segan et al. 2011; Smith et al. 2010) was used to rank the sites worthy of conservation, according to the presence of threatened taxa. A GIS (ESRI 2011) has been used to map the areas of endemism. This tool may be very effective when implemented as part of multi-criteria decision-making framework (Nemec and Raudsepp-Hearne 2013). This combined approach has been tested by an analysis performed with data of threatened and endemic flora species of restricted distribution (regional endemism), in the south of the Iberian Peninsula (Andalusia), one of the territories with the greatest floristic richness in the European continent (Blanca 1993; Domínguez et al. 1996).

Material and methods

Firstly, NDM/VNDM v.3 (hereafter NDM) was used. It is an efficient software program which has been successfully used to determine the areas of endemism of various taxonomical groups (Domínguez et al. 2006; Martínez-Hernández et al. 2014; Szumik et al. 2012). The program uses algorithms based on the concept of areas of endemism (Platnick 1991). Mainly, it is a method which includes georeferenced data about the distribution of the taxa under study (Szumik and Goloboff, 2004). The procedure is basically to assess the consistency of the distribution range of the species of a predefined area (set of cells). The suitability of the species to each area is quantitatively measured by an endemicity index (EI) whose values vary between 0 and 1 (where EI = 1 represents a species whose distribution range is perfectly consistent with the assessment area). Generally, records of a species which are homogeneously distributed within the assessment area will increase the EI of such species, while the presence of records outside the same area will decrease its EI. The level of endemicity of an area is calculated by the addition of the EI of the endemic species present in it. So the more endemic species live in a zone, and the greater the EI, the group of cells will be better supported as area of endemism. This strategy has advantages over other methods designed only to recover hierarchy (Casazza and Minuto 2009; Linder 2001; Tribsch 2004), since it takes into account the geographic distribution of the endemic taxa included in the study, and also it provides a score for each area (addition of EI).

The procedure used by NDM requires, in the first place, the division of the study area into a grid, where the data about the species distribution are represented. In this way, several analyses with different scales for the grid dividing the study area can be implemented. Grid scales depend on the size of the study area and other suitable discretionary criteria such as the amount of taxa studied, or the scale of the available corological information of these taxa. However, for the sake of objectivity, firstly it can be used the optimal grid scale calculated automatically by NDM for the data distribution. Afterwards it is used lower resolution scales, i.e., multiples of the optimal grid scale. In this manner, different results for each grid cell size are obtained. The second step is to execute the option available in NDM for the creation of consensus areas (Aagesen et al. 2013). The consensus areas unite information which is contained in the resulting individual hypotheses. A consensus area encloses individual areas of endemism that have in common a percentage of endemic species (defined by the user). The majority rule criterion implemented by the program was used: a territory or group of adjacent cells forms a consensus area as long as they have at least the 50% of their endemic species in common. The third step is to conduct a database of each of the solutions obtained. This database collected the data concerning the species included in the area of endemism: EI, number of cells covered and solutions grouped by the consensus areas test.

Secondly, MARXAN v.211 (hereafter MARXAN) was used. This is a program designed to ensure the prioritization of species and ecosystems in the management of biodiversity conservation (Ball et al. 2009; Possingham et al. 2000). The program aims at producing an optimal representation of biodiversity features at the minimum cost (McDonnell et al. 2002). It operates with the algorithm Simulated Annealing (Kirkpatrick 1983). This method progressively improves the final solution by selecting the group of sites which proportionally most reduces the total cost.

The endemic level of each taxa was reckoned by a weighting procedure. Following premises established by Tucker et al. (2012) about the inclusion of both geographic and evolutionary rarity in conservation prioritization, the relative parameters of the Continuous Rarity were entered (Gaston 1997) according to the grid size used. The Continuous Rarity (or Stenochory Level) is a way of assessing the rarity of each grid; it measures in what proportion a species is endemic. The Continuous Rarity of a grid is calculated by adding the rarity of each taxa present in it. The rarity of each species is obtained by calculating the inverse of the number of grids where the species appears. Thus, the greater the number of rare species (with limited distribution) presents in a grid, the higher the Continuous Rarity of this grid. This criterion has previously proved to be one of the most appropriate as a species penalty factor in the selection of reserve areas (Martínez-Hernández et al. 2011). All the species had the same occurrence target (target =1) in order to achieve that at least one site of each species was selected by MARXAN. Any aggregation factor or boundary length modifier was not used; because the final solution was adjusted to the distribution of the consensus areas proposed by NDM. The selection procedure was iterated 1000 times in the three different grid scales, as well as the NDM program. The parameters used in Simulated Annealing procedure were the "Heuristic" option, based on species richness; the "Temperature Decrease"(10000); and the "Adaptative Annealing" option with program default parameters. Both the Best solution, which determines the sites present in the final selection, and the Summed solution, the number of times a site was selected, were considered. The Summed solution provided an index of irreplaceability of each site, which is defined as a frequency of site selection in the overall number of MARXAN runs (Pressey et al. 1994; Pressey and Taffs 2001).

Finally, the consensus areas proposed by NDM were checked against the areas obtained with MARXAN (Fig. 1). The NDM consensus areas were used as additional conservation features (aggregation factor) and locked the grid cells where they occurred to be included in MARXAN solution. An example of this innovative methodology is shown in Fig. 2. The programs were integrated considering firstly the spatial coincidence of the selected cells by both software, and secondly, the combination of the EI (NDM) and irreplaceability index (MARXAN). The highest number of coincident cells and the highest values of EI and irreplaceability indexes were the criteria used to decide the final design of the selected areas of endemism (EPAs).

Case study: Endemicity areas for threatened endemic vascular flora in the south of the Iberian Peninsula

Study area

The Mediterranean basin is a world biodiversity hot spot (Médail and Quézel 1997; Quézel and Médail 1995). The Iberian Peninsula and Andalusia in particular, have an outstanding natural value (Aedo et al. 2013; Médail and Diadema 2009; Médail and Quézel 1999; Mota et al. 2002). The climate is Mediterranean with severe frequent summer and winter droughts. However, there are also enclaves such as Sierra de Grazalema with annual rainfall records of over 2200 mm. The altitudinal gradient of this area extends from sea level to 3479 m. The presence of an enormous variety of substrates (siliceous outcrops, volcanic materials and diverse Quaternary substrates) has not only provided a refuge for palaeoendemic taxa but has also encouraged speciation processes. Biogeographically, the territory can be divided into three large units. The largest one is the so-called Betic province which includes all the high mountain peaks generated during the Alpine orogeny and the corresponding intermountain depressions. The Guadalquivir River valley is also included in this unit. The Lusitan-Extremadurean province, which encompasses the elevations of the Palaeozoic base, is located to the north of this valley. Finally, the semiarid territories of the Murcian-Almeriensian province are located to the east of the Betic unit (Rivas-Martínez et al. 2007).

Data sources

The taxa used for the recognition of areas of endemism must have restricted distribution (Platnick 1991; 1992). This geographical restriction is mentioned in criterion B of the IUCN as a requirement for determining the risk of extinction of species (IUCN 2001). In the light of this premise, we drew up a catalogue of 201 species and subspecies (113 genera) of endemic vascular flora found in the Andalusian territory, all of them in one of the following threat categories Critically Endangered (CR), Endangered (EN) or Vulnerable (VU) (Cabezudo et al. 2005). The nomenclature is drawn from Blanca et al. (2009), and the biogeographical terms from Rivas-Martínez et al. (2007). The list generated a data base with 3058 records of the distribution of the taxa. Biological databases are useful ecological research tools for biodiversity studies (Bruno et al. 2012). Plant records were georeferenced in the Universal Transverse Mercator (UTM) projected coordinate system, in the European Datum ED50, at 1 km² scale (see Supplementary Material 1). The distribution of taxa was inferred from bibliographic information (Anthos 2012; Blanca et al. 2009; Castroviejo 1986-2010; Gbif.es 2013; Valdés et al. 1987), herbaria (GDA, HUAL, JAEN, MGC, MUB) and field surveys (Mota et al. 2010; Pérez-García et al. 2009). These latter two sources allowed us to extend and validate the information collected previously. Only observed occurrence samples were considered to calculate the EPAs. Although the available information on the distribution of species had a 1 km² resolution, the grid size closest to the one suggested by NDM was 5x5 km. In this manner, different results were obtained with tests made with grid cell sizes of 5x5, 10x10 and 15x15 km.

Results

Firstly, the results of the analysis using the NDM program for the 5x5 km grid cell size gave eight sets. Each set contained between 12 and 45 threatened endemic species, which were found in areas covering between four and twelve grid cells. The EI for the areas selected had values ranging from 2.2 to 4.2. In this particular case, the peaks of Sierra Bermeja, the peaks of Sierra de Gádor, the calcareous part of Sierra Nevada, the siliceous core of Sierra Nevada and the massif of Sierra Tejeda y Almijara, were selected as the areas of endemism. On the other hand, the test with the10x10 km grid cell size provided solutions which contained between 14 and 61 threatened endemic species; they were distributed in areas covering between three and eight grid cells. The EI rates for the areas selected had values ranging from 2.5 to 8.1. The findings were similar to the previous case, except that they provided 15 sets as a solution and contemplated three areas of endemism (Sierra de Grazalema, Sierra de las Nieves-Sierra de Alcaparaín y Aguas and the peaks of Sierra de Baza) which were not considered in the 5x5 km grid cell case. Besides, the test conducted with the 15x15 km grid cell yielded 33 sets. The EI values ranged from 2.3 to 10.3.Thisareas were distributed in groups of four up to fourteen grid cells, with populations of 11 up to 80 threatened endemic species, depending on the selected area. These findings included those obtained in the two previous cases, and also provided three new areas of endemism. They were the Parque Natural Cabo de Gata-Níjar, the depression of Baza and Sierra de Cazorla y Segura.

Secondly, NDM summarized the individual findings. For the 5x5 km grid a group of seven consensus areas was obtained, four of them identical to the original results (Sierra Bermeja, Sierra de Gádor, Calcareous Sierra Nevada, Sierra Tejeda y Almijara), whereas the other three defined the areas proposed for siliceous Sierra Nevada with greater precision. The consensus test for the 10x10 km and the 15x15 km grid integrated the solutions in ten and eleven consensus areas respectively.

Thirdly, MARXAN provided different solutions widely distributed over the area of Andalusia depending on the grid size. MARXAN findings included some cells belonging to the areas of Sierra Bermeja, Sierra Tejeda y Almijara and the calcareous part of Sierra Nevada more frequently on a 5x5 km scale. In the case of the 10x10 km grid, Sierra de Grazalema, Sierra de Gádor and the connecting area between the peaks of Sierra Nevada and Sierra de Baza obtained higher irreplaceability indexes than on other scales. Lastly, areas such as the siliceous part of Sierra Nevada, Sierra de Cazorla and Segura, Cabo de Gata, the Hoya de Baza and the area made up of the *sierras* of Bermeja, Nieves, Grazalema, Alcaparaín y Aguas stood out more on a 15x15 km scale.

Table 1 and Supplementary Material 2 show the results for the areas of endemism selected in the three scales used. Table 2 shows the summary of selected grid cells by MARXAN, the sum of irreplaceability indexes and the relationship between the cell size used and the percentage of coincidental solutions in both methods. Fig. 3 shows the solutions obtained using the combination of programs NDM and MARXAN.

Eleven areas of endemism EPAs have been identified in our study area. One of the most interesting results of our analyses is that they have led to the identification of different areas of endemism within a continuous territory, such as that of Sierra Nevada. Taxa such as *Armeria filicaulis* subsp. *nevadensis*, *Thlaspi nevadense* and *Armeria splendens* belong to another group of Nevadensian endemic species which connected the western peaks of Sierra Nevada with the eastern peaks of the same range. Likewise, the endemic species *Artemisia alba* subsp. *nevadensis*, *Pinguicula nevadensis* and *Narcissus nevadensis* subsp. *nevadensis* justified the solution of the peaks of Sierra de Baza and their relationship with the Sierra Nevada massif (Olmedo Cobo 2012; Peñas et al. 2005; Pérez-García et al. 2012). On the other hand, the calcareous part of Sierra Nevada, despite its broad and seamless geographical contact with the siliceous portion of the range, has exclusive endemic species, such as *Erodium boissieri*, *Lomelosia pulsatilloides* subsp. *pulsatilloides* and *Helianthemum pannosum*, which were decisive for the determination of this area of endemism. The results, Sierras de Tejeda y Almijara, with endemic species such as *Anthyllis plumosa*, *Hieracium texedense* and *Eryngium grossii*, and Sierra de Grazalema, with *Campanula specularioides*, *Koeleria dasyphylla* or *Fumana lacidulemiensis* are also examples of areas of endemism located on calcareous substrates. The areas of endemism of Sierra Bermeja and its adjoining elevations, with the presence of *Abies Pinsapo*, *Centaurea lainzi* and *Centaurea haenseleri*, are also particularly noteworthy.

Discussion

Complementation of the NDM and MARXAN software packages

Authors such as Kelley et al. (2002) have already suggested combining programs in order to prioritize natural areas according to their biodiversity. Other authors have used this strategy for the selection of specific nature reserves (Jiménez Martínez et al. 2009; Kirkpatrick 1983; Mendoza-Fernández et al. 2010; Perez-García et al. 2007). In this cases the software used, SITES (Andelman et al. 1999), ResNet (Aggarwal et al. 2000), or MARXAN, implement heuristic or meta-heuristic procedures for the most efficient nature reserve selection. However, this study is the first approximation for determining areas of endemism that combines two kind programs not created with common aims. The initial sets of cells are screened under the endemicity criterion using NDM in a computationally fast way. Then MARXAN is used to achieve completeness and efficiency of the areas of endemism in a computationally intensive phase. The combined use of programs NDM and MARXAN makes it possible to relate sites for threatened taxa protection with areas of endemism. In addition, this combined strategy allows the implementation of different working scales so that the results are objective and flexible, which is clearly advantageous when it comes to selecting sites for conservation.

The use of the NDM program itself has some drawbacks. Although the available resolution of the spatial distribution of taxa was 1x1 km, we could not reach this scale to process the data. In this sense, it is worth pointing out that this method works well for larger areas but is less satisfactory when applied to more restricted areas where the flora is well known. The endemic species richness which defines the different areas of endemism is higher or lower depending on the grid scale used. As a result, the boundaries, size and number of the areas of endemism plotted in this manner tend to be fuzzy and follow no regular pattern. This shortcoming of the NDM program has already been studied (Casagranda et al. 2009). The analyses conducted with the MARXAN program are a useful complement when it comes to fine-tuning the selection in each area of endemism and reducing to a minimum the drawbacks of the NDM program. MARXAN selects the array of grid cells exhibiting the highest efficiency records, and ranks the selected areas by their irreplaceability index. This makes it possible to make a more accurate and flexible selection of more specific areas within each area of endemism, according to the scale. The analyses carried out with MARXAN support, largely, the solutions obtained with NDM, since all areas of endemism included irreplaceable grid cells. Admittedly, the irreplaceability index suggests a different adjustment for each area of endemism according to the grid scale selected. In our study case, the increase in the coincidences between NDM solutions and MARXAN solutions suggests that the best option is the 15x15 km scale. However, the areas that the NDM program selects with this scale are very large and difficult to protect unless they are considered as national parks or natural parks.

The combination of both methods can be of great help in determining large protected spaces, such as national or natural parks. In these cases, the areas of endemism could serve as the decisive criterion. However, the selection of grid cells with MARXAN is a reliable tool when it comes to complementing the protected areas network with protection statuses of smaller areas, such as *Parajes Naturales* or others already envisaged in regional provisions. For the creation of reserves, the areas corresponding to areas of endemism but including no site selected by MARXAN could be considered buffer areas and act as ecological corridors. Nevertheless, the ideal approach would be to reach a consensus between both strategies, which has already happened in many cases, as we have shown.

EPAs in the South of the Iberian Peninsula

Except for the Natural Park of Cabo de Gata-Níjar, located in the semiarid South East, all the EPAs selected in the study case were located in the Betic ranges and neighboring depressions. Both territories (Betic ranges and semiarid SE) are easily distinguishable from the rest of the Iberian territories (Moreno Saiz et al. 2013) and belong to well-defined biogeographical units (Rivas-Martínez et al. 2007). Likewise, the results testify to the fact that the Andalusian Betic ranges are one of the richest areas of plant endemicity in the Mediterranean basin. With the exception of Sierra Nevada, the mountain massifs of the Betic ranges have peaks of small extension separated one from another. As a result, the landscape is like a high archipelago rather than a continent-island (Mota et al. 2002). The enormous vegetal richness of the territory has been heavily conditioned by the geographical location of the area. A genuine N-S (Europe and Africa) and E-W (areas under Atlantic influence and areas of the western Mediterranean) crossroad, the region has aided the connection of several different floristic territories (Mota et al. 2002; Peñas et al. 2005).

The siliceous part of Sierra Nevada stands out among the EPAs. The NDM solutions for the Sierra Nevada massif were multiple, some of them completely complementary in terms of floristic composition, but of variable dimensions depending on the scale. This EPA showed a floristic relationship with Sierra de Baza massif which has been supported by several research studies (Olmedo Cobo 2012; Peñas et al. 2005; Pérez-García et al. 2012). This has advantages for the area, because there are flexible options for its management (Sarkar et al. 2002), especially considering that alpine ecosystems have been identified as particularly sensitive to threats from global change (Franzén and Molander 2012). Sierra Nevada is the most important natural EPA for the endemic flora of the Betic ranges (Blanca 2002; Pérez-García et al. 2007). The relict confinement of Arctic-Alpine taxa, the diversity of habitats and the height gradient (Blanca et al. 2002) produced speciation processes. This idea is in accord with the ideas of Morrone (2001) and Casazza et al. (2008) that areas of endemism represent historical entities. Examples of similar isolation producing great richness in endemic species can be found in other biodiversity hot-spots, such as the tropical forests of the eastern slopes the Andes or some oceanic islands in the Pacific (Gillespie et al. 2013; Särkinen et al. 2012).

The clear distinction obtained between EPAs located on siliceous and calcareous sections of Sierra Nevada massif is relevant. The main dolomitic outcrops that produced this separation are home to particular floras as a result of speciation processes induced by extremely stressing environmental conditions and the isolation brought about by this kind of substrates (Mota et al. 2008). Although these solutions belong to the same mountain massif, it is interesting that two closely connected EPAs emerge as a result of the different substrates (Mota 1990). This outcome reveals the significant role played by two factors in the genesis of endemic species, namely, the geographical factor (isolation) and the edaphic factor (ecology). Other EPAs on dolomitic substrates are the solutions made up of Sierra Tejeda y Almijara and Sierra de Grazalema, a territory palaeogeographically isolated by the Guadalhorce corridor (Martín et al. 2001; Medina-Cazorla et al. 2010) with numerous floristic connections with the Tingitan territory (Rodríguez-Sánchez et al. 2008). Otherwise, the serpentines of the territory of Sierra Bermeja have brought about an edaphism which imposes heavy restrictions on the flora (Krukeberg 1984). These facts would endorse the idea about plant endemicity is closely linked to the nature of the geological substrate.

On the other hand, the Sky-Island effect (Riemann and Ezcurra 2007) in Sierra de Gádor could account for the selection of this mountain as an EPA. The location of this massif, surrounded by semiarid territories, and its high altitude –only just below the peaks of Sierra Nevada–have given rise to numerous endemic taxa. The peaks of this range are protected as SCIs. However, the whole range, from sea level to the highest peaks, is significant as anarea of endemism with a large number of threatened species. Finally, the mountainous natural areas, such as Sierra Grazalema, Sierra Nieves, Sierra Cazorla-Segura, together with the Andalusian semiarid areas, were gaps in the results of the large scale analyses as a result of the greater dispersal of the endemic species in these areas. Nonetheless, all these territories are included in the Protected Natural Areas Network of Andalusia under the status of Natural Park. This is not the case of EPA of Hoya de Baza, an arid territory whose relevance for the conservation of Spanish flora has already been highlighted by several analyses (Mendoza-Fernández et al. 2014b).

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Tables

Table 1 Territories selected as areas of endemism according to the three working scales used. Boxes in bold-face represent the best solutions according to the EI obtained by means of NDM for the characteristic species of the areas of endemism, the number of solutions enclosed in the Consensus areas, and the number of Summed solutions, Best solutions and their irreplaceability indexes obtained by MARXAN.

Table 2 Total number of grid cells proposed as the EPAs by the two programmes according to the grid size. Total scores achieved for EI and irreplaceability index. Percentages of coincidental grid cells obtained.

Figures

Figure 1 Chart of the methodology proposed to determine and analyze EPAs.

Figure 2 Chart of the methodology proposed for the threatened endemic vascular flora in the area of Sierra Nevada (south of the Iberian Peninsula). Grid scale: 5x5 km.

Figure 3 (a) NDM/VNDM results. (b) MARXAN results. (c) EPAs obtained by the combination of programs NDM/VNDM and MARXAN.

Table 1 Territories selected as areas of endemism according to the three working scales used. Boxes in bold-face represent the best solutions according to the EI obtained by means of NDM for the characteristic species of the areas of endemism, the number of solutions enclosed in the Consensus areas, and the number of Summed solutions, Best solutions and their irreplaceability indexes obtained by MARXAN.

TERRITORIES	NDM			MARXAN		
	EI	**Consensus Areas**	**Cells**	**Summed**	**Best**	**Irrep.**
5x5 km grid						
S. Bermeja	2.7	1	4	3	2	1000 979
S. Gádor	2.4	1	6	6	1	876
Siliceous S. Nevada	3.9	1	5	5	3	1000 1000 289
Calcareous S. Nevada	2.5	1	5	3	2	1000 1000
Siliceous S. Nevada	2.4	1	6	5	3	1000 1000 289
S. Tejeda & Almijara	2.7	1	12	12	3	1000 979 440
Siliceous S. Nevada	4.3	2	10	8	4	1000 1000 493 289
10x10 km grid						
S. Bermeja	2.5	1	3	3	1	1000
S. Tejeda & Almijara	4.3	3	6	6	2	1000 429
S. Grazalema	2.5	2	8	6	2	943 194
Siliceous S. Nevada	8.1	1	6	3	3	1000 1000 1000
S. Gádor	3.7	2	8	6	3	1000 745 518
S. Bermeja, S. Nieves, S. Alcaparaín & Aguas	2.7	1	7	5	1	1000
Calcareous S. Nevada	2.5	2	1	1	1	1000
Siliceous S. Nevada & S. Baza	2.5	1	7	4	3	1000

						1000 468
Siliceous S. Nevada	5.6	1	4	3	3	1000 1000 1000
S. Tejeda & Almijara	3.1	1	7	6	2	1000 429
15x15 km grid						
S. Bermeja, S. Nieves, S. Grazalema, S. Alcaparaín & Aguas	4.4	12	14	11	5	1000 1000 907 421 320
S. Gádor	4.2	2	4	3	2	1000 510
Siliceous S. Nevada & S. Baza	6.4	6	13	8	7	1000 1000 1000 1000 1000 1000 1000
S. Cazorla & Segura	3.1	2	7	5	3	1000 1000 970
S. Tejeda & Almijara	5.7	2	6	3	1	997
Siliceous S. Nevada	10.3	3	7	6	5	1000 1000 1000 1000 1000
Calcareous S. Nevada	2.3	1	4	3	3	1000 1000 1000
Hoya de Baza	2.3	1	8	6	2	1000 500
S. Bermeja, S. Nieves, S. Alcaparaín & Aguas	2.4	2	14	9	3	907 421 320
Cabo de Gata	2.6	1	7	3	1	515
S. Cazorla & Segura	2.3	1	11	5	2	1000 362

Table 2 Total number of grid cells proposed as the EPAs by the two programmes according to the grid size. Total scores achieved for EI and irreplaceability index. Percentages of coincidental grid cells obtained.

Grid	NDM cells	NDM EI	MARXAN cells	MARXAN irrep.	Coinc. cells	Coinc. cells %	Coinc. irrep. cells	Coinc. irrep. cells %
5x5	41	21.1	68	11555	16 of 68	23.5	6 of 20	30
10x10	41	37.3	55	15764	20 of 55	36.4	10 of 24	41.7
15x15	71	46.2	35	21954	27 of 35	71.1	14 of 19	73.7

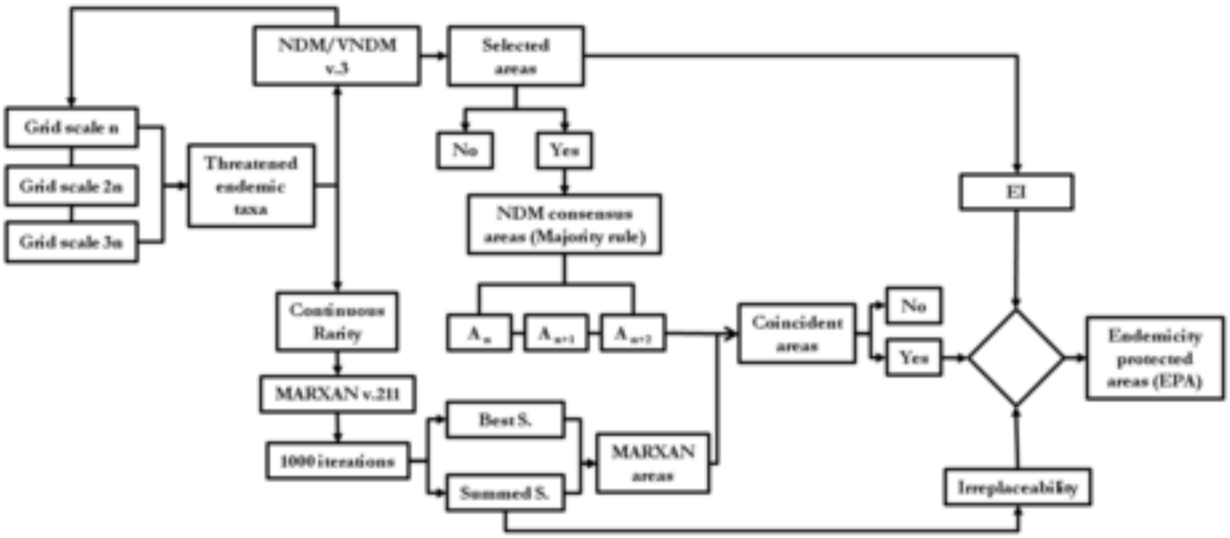
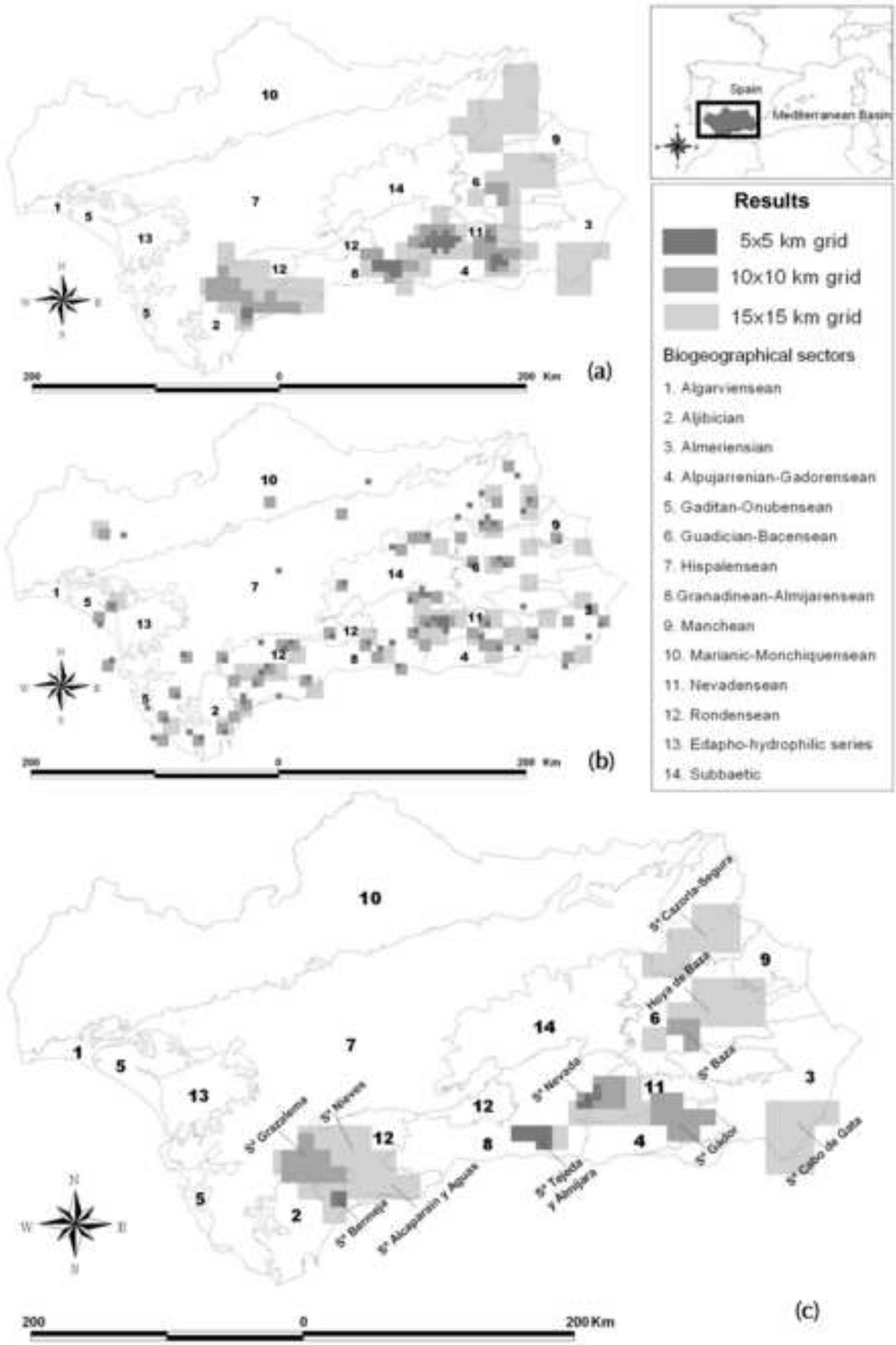

NDM/VNDM v.3
Selected areas
Grid scale n
Grid scale 2n
Grid scale 3n
Threatened endemic taxa
No
Yes
EI
NDM consensus areas (Majority rule)
Continuous Rarity
Coincident areas
No
Yes
Endemicity protected areas (EPA)
MARXAN v.2.11
Best S.
1000 iterations
MARXAN areas
Summed S.
Irreplaceability

Figure 2

A n
A n+1
A n+2
Best solution
EI: 3.915
EI: 2.449
EI: 4.322
NDM consensus areas
NDM-MARXAN EPAs
MARXAN results
Endemic taxa presence
MARXAN Summed solutions
0 - 200
200 - 400
400 - 700
700 - 1000
Irreplaceability: 2289
Irreplaceability: 2289
Irreplaceability: 2782


10
9
14
6
7
1
5
13
11
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12
8
4
5
2
(a)
10
9
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13
12
11
3
12
8
4
5
2
(b)
10
9
S^a Cazorla-Segura
Hoya de Baza
6
14
7
1
5
13
S^a Nevada
11
S^a Baza
3
12
S^a Grazalema
S^a Nieves
12
8
4
S^a Gádor
S^a Cabo de Gata
5
2
S^a Bermeja
S^a Alcaparaín y Aguas
S^a Tejeda y Almijara
(c)
200
0
200 Km
Spain
Mediterranean Basin
Results
5x5 km grid
10x10 km grid
15x15 km grid
Biogeographical sectors
1. Algarviensean
2. Aljibician
3. Almeriensian
4. Alpujarrenian-Gadorensean
5. Gaditan-Onubensean
6. Guadician-Bacensean
7. Hispalensean
8. Granadinean-Almijarensean
9. Manchean
10. Marianic-Monchiquensean
11. Nevadensean
12. Rondensean
13. Edapho-hydrophilic series
14. Subbaetic