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A new method to set conservation priorities in biodiversity hotspots

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Abstract

Prioritization of endemic, threatened species and the habitats where they live is a crucial point of conservation actions, particularly in areas with rich endemic floras. In this study, we have developed a new procedure to define the conservation priorities among endemic plants and habitats by evaluating eight criteria. Five criteria deal with the geographic and ecological range of the evaluated species, whereas the other three refer to threats. After the evaluation of each criterion, we combined the partial scores to obtain a priority index (PI). Finally, we characterized the EU habitat categories of conservation concern on the basis of the average PI value of the plants living in each habitat. We tested the method on a list of 260 endemic plants from a biodiversity hotspot (Sardinia) that had an average PI of 3.66 ± 0.16 . Even if the habitat categories that are most rich in endemic plants were rocky habitats, and coastal/halophytic habitats, the most endangered habitat was coastal sand dunes ($PI = 6.75 \pm 1.15$). The method herein presented is complementary with the application of IUCN criteria. This integrated approach is a concrete solution that adapts IUCN criteria and categories to local contexts.

Keywords: *Biodiversity hotspots, conservation, endemic plants, Habitats Directive, IUCN criteria and categories, Mediterranean Basin, Priority Index*

Introduction

Biodiversity hotspots are defined as areas where exceptional concentrations of endemic species undergo exceptional loss of habitat (Myers 1988, 1990; Myers et al. 2000). This definition opens the way for a new strategy of nature conservation, focusing on two main targets: endemic species of a given area, and the habitats where they live (Pimm & Raven 2000).

Unfortunately, national Red Lists of threatened animal and plant species, prepared according to the criteria of the IUCN (Mace & Lande 1991; IUCN 2001, 2003), cannot be used directly to set conservation priorities (Possingham et al. 2002; Keller & Bollmann 2004; Fitzpatrick et al. 2007), although they adequately reflect the extinction risk of species within a country (Schnittler & Gunther 1999; Keller & Bollmann 2004). First, IUCN criteria are useful to define the conservation status of a given species at the global level, but not to create a ranking list of species based on their conservation priority

(Gauthier et al. 2010). Second, the application of IUCN criteria at the local level is sometimes challenging because the criteria prescribed are conceived with the aim of evaluating the extinction risk of a species at the global level (Mace & Lande 1991; Gärdenfors 2001; IUCN 2001; Mace et al. 2008). Consequently, even if IUCN criteria were proven to be effectively applied to peripheral isolated plant populations (Abeli et al. 2009), we think that they are not fully useful to set conservation priorities when dealing with abundant endemic floras; priority setting for rare species does not equate to the elaboration of Red Lists based on extinction risk (Gauthier et al. 2010).

Because of these limitations, several countries have tried to adapt IUCN criteria to local requirements (Miller et al. 2007; Rana and Samant 2010): a regional (Gärdenfors et al. 2001) and national (Gärdenfors 2001) approach is therefore needed. Moreover, in the European Union, directives have to be transposed into national law and implemented by each member state; hence, there is a growing need to

develop and test advanced classification methods and spatial indicators to rapidly accomplish monitoring and management tasks in the context of the NATURA-2000 programme from the continental to the local level (Bock et al. 2005).

When dealing with abundant endemic floras, it is appropriate to define a methodology that should be both strict and simple at the same time, and it should aim at identifying conservation priorities with respect to both the global perspective and the IUCN categories and criteria (Martin 2009). As recommended by some authors (Sapir et al. 2003; Brooks et al. 2006; Wilson Kerrie et al. 2009), establishing priority lists of species and habitats is of utmost importance while allocating financial resources to conservation programmes. Furthermore, priority lists of species and habitats of conservation concern are useful to awaken politicians, managers and the general public to precise objectives. This seems to be a necessary and crucial option, particularly in areas of limited extension that are rich in endemic plant species, such as islands within biodiversity hotspots.

The Mediterranean region hosts a flora of around 25,000–30,000 flowering plants and ferns and has been identified as one of the world's 34 biodiversity hotspots (Quézel & Médail 1995; Myers et al. 2000; Mittermeier et al. 2004). In this area, which includes 25 independent nations (including the British Gibraltar and the constituting Palestine), it is possible to recognise 10–11 hotspots (Médail & Quézel 1997; Vela & Benhouhou 2007; Nikolić et al. 2008; Médail & Diadema 2009), constituting about 22% (515,000 km²) of the total surface of the Mediterranean Basin and including about 5500 narrow endemic plants (Médail & Quézel 1999). One of these Mediterranean hotspots is represented by the Tyrrhenian islands (Balearic Archipelago, Corsica, Sardinia and Sicily).

In this study, we have developed a new procedure to define and concisely express the conservation priorities among endemic plants and habitats at the local level. By doing so, we have given importance to the spatial scale, which is the focal point in assessing conservation priorities (Hartley & Kunin 2003). Consequently, we have followed an integrated approach (i.e. using some of the IUCN criteria that have been adapted to the local scale and some other criteria not included in the IUCN scheme) as recently proposed by several authors (Dunn et al. 1999; Keller & Bollmann 2004; Nature Serve 2007; Gauthier et al. 2010). The following are the specific objectives and outcomes of this study: (1) to develop a new method for assessing the conservation priorities when working with abundant endemic plant groups; (2) to test the proposed method on a list of endemic plants from a biodiversity hotspot

(Sardinia); (3) to classify the habitat types of conservation concern (those included in the Annexe I of the EU Habitats Directive 92/43) on the basis of the conservation priority of plant species living within them.

Materials and methods

Study area

Sardinia, the second largest island in the Mediterranean sea (24,090 km²), lies in the central part of the western Mediterranean Basin, between the Italian and the Iberian peninsulas (from east to west, respectively) and between Corsica and the Provençal-Ligurian coasts (to the north) and Sicily and northern Africa (to the south).

In the recently published checklist of the Italian Vascular Flora (Conti et al. 2005, 2007), 2494 plant entities have been reported for the island. Moreover, new taxa are continuously being discovered and described. With a rough estimate of about 2500 vascular plants, Sardinia, therefore, shows a floristic density of 103.5 species/1000 km². The endemic flora comprises 347 endemic plants *sensu lato* (i.e. endemic of Sardinia and other insular territories of the western Mediterranean subregion, 13.9%), of which 155 (6.2%) are exclusive (endemic plants *sensu stricto*) to the island (Bacchetta et al. 2005).

The Sardinian flora is peculiar also in terms of the originality of genetic inheritance: widespread (Meloni et al. 2006) and endemic (Bacchetta et al. 2008; Mameli et al. 2008). This is a result of the unique geological history that played an essential role in shaping plant biodiversity on Sardinia and adjacent islands (Mansion et al. 2008). The historic-genetic elements of the Sardinian flora indicate its inclusion within the biogeographical Mediterranean region (Takhtajan 1986) and within the western Mediterranean subregion as a consequence of a common geological history (Cardona & Contandriopoulos 1979; Cherchi & Montadert 1982). Within the western Mediterranean subregion, Sardinia belongs to the Italo-Tyrrhenian superprovince (Ladero Alvarez et al. 1987), and to the Sardinian-Corsican province (Arrigoni 1983; Ladero Alvarez et al. 1987; Bacchetta & Pontecorvo 2005; Bacchetta et al. 2009).

The recognition of an autonomous Sardinian-Corsican province is based on the large number of endemic plants exclusive for the two islands, noteworthy among which are the two monotypic genera *Morisia* Gay and *Nananthea* DC. Several Sardinian endemic species have led Arrigoni (1983) to recognize a Sardinian subprovince, which was later confirmed by other authors (Bacchetta &

Pontecorvo 2005; Rivas-Martínez 2007; Bacchetta et al. 2009).

Criteria for the evaluation of conservation priorities among endemic plants

The method used to assess the conservation priorities of plant taxa is based on the evaluation of eight criteria, each of which can receive a score from 1 to 5: endemism (E), number of populations (NP), area of occupancy (AOO), population size (PS), ecological range (ER), natural threats (NTs), anthropogenic direct and indirect threats (ATs) and decline rate (DR). Some of the selected criteria are those proposed by the IUCN (2001), such as NP, AOO, PS and DR. For these criteria, we adopted the evaluation scale that was previously proposed by the IUCN, with appropriate adaptations to many of them to suit the spatial scale of the Mediterranean islands, where numerous narrow endemic plants are present within restricted spatial ranges. E, ER, NTs and ATs were also evaluated, although they are not included among the IUCN criteria. The first five criteria adopted here (E, NP, AOO, PS and ER) deal with the geographic distribution of a given taxon, whereas the other three (NTs, ATs and DR) refer to threats affecting each evaluated taxon. Moreover, we considered it useful to refine criteria B and D of the IUCN, which include very large areas, at least for sessile organisms, thus making the definition of conservation priorities difficult on the local scale (Keith 1998).

All the adopted criteria were evaluated on the basis of both the available data and direct observations carried out during the previous 10 years or three generations. Note that almost all the endemic plants of Sardinia have been well studied in the recent decades, at least from the distribution point of view. Therefore, a large amount of scientific literature is available with a great deal of data suitable for this type of evaluation. Among the numerous scientific papers already published, the series “*Le Piante Endemiche della Sardegna*” edited by Arrigoni et al. (1976–1992) is noteworthy, and it includes 202 endemic plants. Quantitative and qualitative information included in such papers are at the basis of the prioritization method adopted here. In addition, the distribution maps in these papers on Sardinian endemic plants have proven to be very useful for determining some of the parameters adopted here, such as NP, AOO and PS.

As the detection of criteria is useful for the evaluation of the geographic distribution of a given taxon, in addition to IUCN parameters (2001) we followed Rabinowitz (1981) as suggested by Hartley and Kunin (2003), particularly for PS and ER. The criterion “geographic range size” used by Rabinowitz (1981) was not included as such because we consider it as the result of the combination of AOO with NP. Criterion E is not included in those used by Rabinowitz (1981) and by the IUCN (2001), but its use was suggested by Hartley and Kunin (2003). In comparison to the system used by Harte and Kinzig (1997) for the realization of a “scale of endemism”, we preferred an integrated biogeographical approach, which we consider to be more suitable for the definition of this criterion (E) in insular environments. Furthermore, we think that our approach is preferable in order to invest local communities with a responsibility for biodiversity conservation, as suggested by Keller and Bollmann (2004).

Endemism (E)

This criterion is based on biogeographical categories that synthetically express the local responsibility level (see above). The application of this criterion is based on the simple assumption that the narrower the range of a given taxon, the greater the local responsibility and, therefore, the greater its conservation priority (see also Gauthier et al. 2010 for the concept of Regional Responsibility). On the basis of the general chorological classification and the biogeographical units, the scale that has been considered for endemic plants limited to a specific biogeographical province (as defined by Takhtajan 1986; Rivas-Martínez 2007; Medina-Cazorla et al. 2010) is as follows:

Endemism (E)

• A taxon distributed in all parts of the biogeographical province (Sardinia, Corsica and Tuscan Archipelago) = 1;

• A taxon limited to Sardinia and Corsica = 2;

• A taxon limited to a subprovince (Sardinia) = 3;

• A taxon limited to a sector or subsector (e.g. Sulcis-Iglesiente) = 4;

• A narrow endemic taxon (exclusive of a district or a limited area) = 5.

Number of populations (NP)

A population includes all the individuals belonging to a given taxonomic unit, which interact with each other within a limited area and are able to reproduce, thereby maintaining unaltered their genetic inheritance (Fowler et al. 1998). Following this concept, we established a scale partially based on the IUCN (2001) criteria, which is modified and adapted to insular Mediterranean areas:

- NP: ≥ 20 = 1;
- NP: 11–19 = 2;
- NP: 6–10 = 3;
- NP: 2–5 = 4;
- NP: 1 = 5.

Area of occupancy (AOO)

We adopted the following scale for Mediterranean islands (modified from IUCN 2001):

- AOO: $> 100 \text{ km}^2 = 1$;
- AOO: $> 10\text{--}100 \text{ km}^2 = 2$;
- AOO: $> 1\text{--}10 \text{ km}^2 = 3$;
- AOO: $> 0.1\text{--}1 \text{ km}^2 = 4$;
- AOO: $\leq 0.1 \text{ km}^2 = 5$.

The modification of the IUCN ranges is necessary because even the most restrictive IUCN level (VU D2 = AOO $< 20 \text{ km}^2$) leads to consider many well-distributed plants on Sardinia as vulnerable, with consequent levelling out of the results of the assessment. The risk of overestimating the threat of endemic species living on islands was previously highlighted for the Canary Islands (Martin 2009).

Population size (PS)

The total number of individuals in a given taxon with reproductive capacity is considered as PS. We have partially followed the levels established by the IUCN (2001), and the following scale is herein proposed:

- PS: $> 50,000$ individuals = 1;
- PS: $5001\text{--}50,000 = 2$;
- PS: $501\text{--}5000 = 3$;
- PS: $51\text{--}500 = 4$;
- PS: $1\text{--}50 = 5$

Ecological range (ER)

With reference to the ecological range of each taxon, we adopted a scale that considers the number of habitats in which the taxon can be found. A habitat refers to a distinctive set of physical–environmental factors that a species uses for its survival and reproduction. Habitat use refers to the manner in which an individual or species uses the respective habitat to meet the various needs in its life history (Block & Brennan 1993). Following the proposal of Andreas and Lichvar (1995), the following scale was used in this study:

- ER: > 4 habitats = 1;
- ER: 4 habitats = 2;
- ER: 3 habitats = 3;
- ER: 2 habitats = 4;
- ER: 1 habitat = 5.

Natural threats (NTs) and anthropogenic threats (ATs)

The assessment of the conservation priorities includes the distinction between natural threats (NTs)

and anthropogenic threats (ATs) beginning from the IUCN Threats Classification Scheme, Version 3.0 (IUCN 2009). It is important to distinguish between the two types of threats because (1) the spatial-temporal scales at which the two types of threats act are often very different and (2) the two types of threats need to be addressed in different ways. As an example, ATs make it difficult to build a widespread approval needed to safeguard the endangered species because they are quite often linked to economic interests. We can therefore assume that ATs and NTs act at different spatial and temporal scales.

Here, we consider the following as NTs: natural factors and those that arise at the non-local level, even if they have an anthropogenic origin, and act indirectly on plant populations. Therefore, in addition to typically natural factors such as predation (herbivory, phytophagy and parasitism), intra- and inter-specific competition, natural hybridization and natural calamities (earthquakes, volcanic eruptions and extreme weather events) in the category NTs, we have included factors such as the development of the shrub and forest vegetation caused by land use change and non-localized anthropogenic factors such as air pollution, acid rain and global climatic change.

Instead, in ATs, we consider those factors that directly originate from human actions having consequences that are direct and confined to a place (Salafsky et al. 2008), such as hydrogeological upheaval, pollution of soil, lakes, rivers and water table, wetland reclamation, agro-sylvo-pastoral activities, urban and infrastructure development, sport activities, tourist pressure, arsons, introduction of allochthonous species and human-induced hybridization.

On the basis of the recurrences and intensities of disturbances, and also according to IUCN categories (2001), we distinguished the following five levels:

- Very low (disturbance not present or very sporadic and slight, which is not significant) = 1
- Low (disturbance is present at low intensity and/or frequency; thus, it does not modify the habitats nor lead to a significant decrease in the PS, NP or AOO. This level should be distinguished from the former because an increase in the frequency or intensity of disturbance may cause a significant decrease in PS, NP or AOO.) = 2
- Moderate (VU E). A quantitative analysis showing a probability of extinction in the wild of at least 10% within 100 years = 3
- High (EN E). A quantitative analysis showing a probability of extinction in the wild of at least 20% within 20 years or five generations, whichever is the longer (up to a maximum of 100 years) = 4

- Extreme (CR E). A quantitative analysis showing a probability of extinction in the wild of at least 50% within 10 years or three generations, whichever is the longer (up to a maximum of 100 years) = 5.

Decline rate (DR)

Criteria for the decline rate of species follow those of the IUCN (2006a). A continuing decline is a recent, current or projected future decline (which may be smooth, irregular or sporadic), which is liable to continue unless remedial measures are taken. Fluctuations are not normally counted as continuing declines, but an observed decline should not be disregarded as a fluctuation unless there is evidence (IUCN 2001).

- DR: $\leq 10\%$: reduction of the PS by $\leq 10\%$, as verified, estimated, deduced, or suspected in the last 10 years or three generations = 1
- DR: $> 10\% - 30\% = 2$
- DR (VU A2): $> 30\% - 50\% = 3$
- DR (EN A1 + 2): $> 50\% - 80\% = 4$
- DR (CR A2): $> 80\% = 5$.

Priority index (PI)

We consider a crucial point for the evaluation of conservation priorities the net distinction between rarity and threats of the evaluated species (Gauthier et al. 2010). Greater vulnerability and risk of extinction of threatened plant species is based not only on their geographic distribution, but also on a greater influence of genetic factors (Falk & Holsinger 1991; Lande 1995) as well as environmental and demographic ones (Shaffer 1981; Baskin & Baskin 1986), competition and colonization of space and trophic resources, trophic complexity of the community, interaction with one or more limiting resources (Tilman & Pacala 1993), and secondary succession processes in man-influenced ecosystems (Baskin & Baskin 1986). A species that is naturally rare (as are many narrow endemic plants) is not necessarily endangered because rarity is an intrinsic character of many plant groups (Domínguez Lozano & Schwartz 2005), and even floristic contingents of areas such as the Mediterranean Basin (Greuter 1995; Cowling et al. 1996), which is both a refuge and an active speciation area (Verlaque et al. 1997; Médail & Diadema 2009).

We decided to combine the threat and the geographic categories to single out several “typologies of priority”. After evaluating each of the eight criteria, we considered them separately, to obtain two different indexes: the threat index (TI) = NT + (DR + AT) \times 2, varying from 5 to 25, and the

geographical and ecological index (GEI) = E + NP + AOO + PS + ER, varying again from 5 to 25.

In the formula for the TI we decided to emphasize, by doubling the sum of their values, the importance of anthropogenic threats (AT) and decline rate (DR), in view of the fact that the former is often acting more quickly on plant populations than natural threats, while the latter is the expression of the reduction of populations providing quantitative issues to be addressed to ensure their survival.

Then, we classified each evaluated taxon into four threat categories (from A to D), and four geographic categories (from 1 to 4) as follows:

Threat category (TI):

- D: $\geq 5 - 10$;
- C: $\geq 11 - 15$;
- B: $\geq 16 - 20$;
- A: $\geq 21 - 25$.

Geographic and ecologic category (GEI):

- 4: $\geq 5 - 10$;
- 3: $\geq 11 - 15$;
- 2: $\geq 16 - 20$;
- 1: $\geq 21 - 25$.

Finally, we combined the four levels of threat and geographical categories to obtain a priority list composed of 16 priority categories. Each priority category received a score (Priority Index, PI) ranging from 1 to 16, which is proportional to the degree of threat and geographical distribution for a given taxon (Table I). If uncertainty exists for one or more criteria, the taxon for which uncertainty exists is not evaluated and consequently classified under the status not evaluated (NE).

Local endemic flora

In this article, we consider as Sardinian vascular endemics the plant species, subspecies and varieties growing exclusively in the Sardinian-Corsican biogeographical province, including the Tuscan

Table I. Priority index (PI) values obtained by combining the threat index (TI) and the geographical and ecological index (GEI).

| | Threat index (TI) | | | |
|-----------------------------------------|-------------------|----------|-------------|---------|
| | Very high = A | High = B | Average = C | Low = D |
| Geographical and ecological index (GEI) | | | | |
| Very narrow = 1 | A1 = 16 | B1 = 12 | C1 = 8 | D1 = 4 |
| Narrow = 2 | A2 = 15 | B2 = 11 | C2 = 7 | D2 = 3 |
| Average = 3 | A3 = 14 | B3 = 10 | C3 = 6 | D3 = 2 |
| Wide = 4 | A4 = 13 | B4 = 9 | C4 = 5 | D4 = 1 |

Archipelago or smaller inner islands. Vascular plants, which are exclusive to the Sardinian-Corsican biogeographical province, present in Sardinia number 260. Plant names follow the checklist of Italian vascular plants (Conti et al. 2005, 2007) and authors' abbreviations are provided according to Brummitt and Powell (1992). The following abbreviations are adopted for the distribution of plants: Tuscan Archipelago (TA), Corsica (CO) and Sardinia (SA).

In the framework of the project involving the checklist of the Italian vascular flora (Conti et al. 2005, 2007), a specific database has been created for the Sardinian endemic flora, from which we elaborated the list of plants evaluated herein (Annexe I, available from http://www.ccb-sardegna.it/html/down_pub_All.htm). In this continuously updated list, the scientific name, family, biological form and distribution range are reported for each of the 260 evaluated entities. Furthermore, we also indicated whether a taxon is included within the following:

- the Annexe II of the Habitat Directive (European Commission 1992),
- the national IUCN Red List (Conti et al. 1992),
- the local IUCN Red List (Conti et al. 1997),
- the Red and Blue IUCN Lists developed only for those plants included within the Annexe II of the Habitat Directive (Bacchetta 2001),
- the Italian atlas of endangered species (Scoppola & Spampinato 2005),
- the Global IUCN Red List (IUCN 2006b).

In the eight columns of the database, the values of the eight evaluated criteria for each taxon, ranging from 1 to 5, are provided. Finally, the values of TI, GEI and PI are reported on separate columns. The last column of the database indicates the habitat category to which a given species belongs (habitats are indicated by numbers explained below).

Method for the evaluation of conservation priorities among EU habitat types

We assigned each evaluated taxon to a habitat category among the nine categories included in the Annexe I of the 92/43/EEC Directive (European Commission 1992). The categories are as follows: 1 – Coastal and halophytic habitats; 2 – Coastal sand dunes and inland dunes; 3 – Freshwater habitats; 4 – Temperate heaths and scrubs; 5 – Sclerophyllous scrub (matorral); 6 – Natural and seminatural grassland formations; 7 – Raised bogs, and mires and fens; 8 – Rocky habitats and caves; and 9 – Forests. The Sardinian plants evaluated herein are referred to all the habitat categories except the seventh category, which is not present on the island. Furthermore, we established a new class: 0 – Habitat generalist, for

those taxa living in more than one habitat category. For each habitat category, we calculated not only the total number of endemic plants living in that habitat, but also the average PI value (as the average PI among the species living in that habitat).

Results

Conservation priorities and PI of the local endemic flora

Out of the 260 evaluated entities, 10 [*Elymus acutus* (DC.) Thiébaud, *Helichrysum frigidum* (Labill.) Willd., *Limonium multifurcatum* Erben, *Luzula spicata* (L.) DC. subsp. *italica* (Parl.) Arcangeli, *Medicago intertexta* (L.) Mill. var. *tuberculata* Moris, *Ophrys funerea* Viv., *Ophrys scolopax* Cav. subsp. *sardoa* H. Baumann, Giotta, Lorenz, Künkeke & Piccitto, *Senecio siculus* All. var. *nemoralis* (Gennari) Pignatti, *Senecio transiens* (Rouy) Jeanm. and *Senecio vulgaris* L. var. *tyrrhenus* Fiori] belonged to the category NE because one or more of the eight criteria could not be evaluated.

The remaining 250 plants had an average PI = 3.66 ± 0.16 . Of these, 199 belong to threat category D, 41 to category C, 8 to category B, and 1 to category A (Table II and Annex I).

At present, the more threatened Sardinian plants, included within categories A and B, are *Borago morisiana* Bigazzi & Ricceri (A1), *Anchusa littorea* Moris (B1), *Anchusa sardoa* (Illario) Selvi & Bigazzi (B1), *Dianthus morisianus* Vals. (B1), *Polygala sinisica* Arrigoni (B1), *Cerastium palustre* Moris (B2), *Salvia desoleana* Atzei & Picci (B2), *Anchusa crispa* Viv. subsp. *crispa* (B3), *Iberis integerrima* Moris (B3).

Characterization of EU habitat types

The habitat categories most rich in endemic plants (Table II) were: rocky habitats and caves (60 entities) and coastal and halophytic habitats (50). The habitat categories that had the lowest numbers of endemic plants were: coastal sand dunes and inland dunes (13 entities), and forests (16 entities).

Conversely, considering the average PI value for each habitat category (Figure 1), the highest PI (6.75 ± 1.15) is associated with habitat category 2 (coastal sand dunes and inland dunes), and the lowest (1.50 ± 0.18 ; $n = 16$) with the habitat category 0 (habitat generalists). The largest number of A and B species was found in the habitat category 2 (4 entities, 33.3%).

Discussion

In a scenario where the number of species with conservation needs has increased to a level for which

Table II. Number of Sardinian endemic plants, in the nine examined habitat categories, classified in 16 priority levels (NE, A1–A4, B1–B4, C1–C4 and D1–D4).

| Habitat | NE | A1 | A2 | A3 | A4 | B1 | B2 | B3 | B4 | C1 | C2 | C3 | C4 | D1 | D2 | D3 | D4 | Total |
|---------------------------------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-------|
| 0 – Habitat generalist | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 10 | 16 |
| 1 – Coastal and halophytic habitats | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 12 | 23 | 7 | 0 | 50 |
| 2 – Coastal sand dunes and inland dunes | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 1 | 2 | 2 | 0 | 13 |
| 3 – Freshwater habitats | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 3 | 2 | 0 | 1 | 6 | 4 | 3 | 22 |
| 4 – Temperate heath and scrub | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 2 | 0 | 2 | 5 | 7 | 1 | 22 |
| 5 – Sclerophyllous scrub (matorral) | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 2 | 1 | 0 | 1 | 3 | 7 | 2 | 20 |
| 6 – Natural and semi-natural grassland formations | 5 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 14 | 8 | 10 | 41 |
| 8 – Rocky habitats and caves | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 6 | 2 | 0 | 0 | 7 | 28 | 12 | 3 | 60 |
| 9 – Forests | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 3 | 4 | 4 | 1 | 16 |
| Total | 10 | 1 | 0 | 0 | 0 | 4 | 2 | 2 | 0 | 15 | 20 | 5 | 1 | 28 | 87 | 55 | 30 | 260 |

Note: NE, not evaluated.

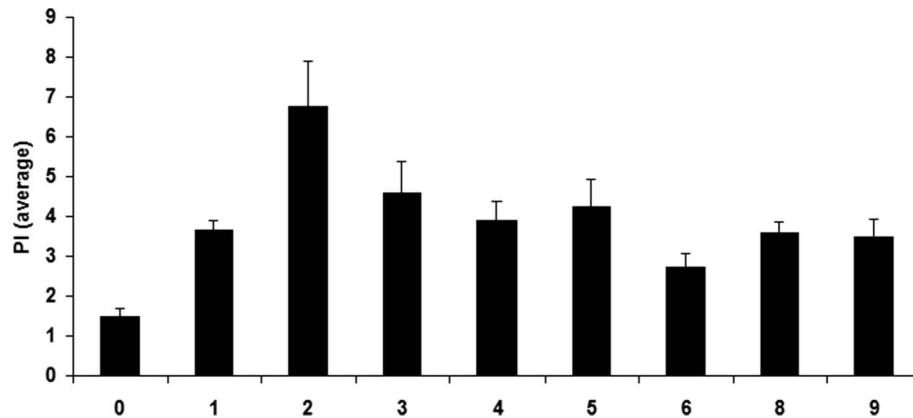


Figure 1. Average value of PI (\pm SE) for the nine examined habitat categories. 0, Habitat generalist; 1, Coastal and halophytic habitats; 2, Coastal sand dunes and inland dunes; 3, Freshwater habitats; 4, Temperate heaths and scrubs; 5, Sclerophyllous scrub (matorral); 6, Natural and semi-natural grassland formations; 8, Rocky habitats and caves; 9, Forests.

the time and resources to elaborate action plans for each individual taxon are no longer available (Pärtel et al. 2005), governments and managers often refer to lists of species and habitats developed on the basis of unclear and unrepeatable procedures. In this study, we present a new and simple method to assess conservation priorities while working with large amounts of endemic species, particularly within biodiversity hotspots. The method includes a biogeographical hierarchy, necessary to determine the conservation responsibility at the local level, without losing sight of a global perspective (Eaton et al. 2005). Concurrent with conservation, an ecological component is also present because we evaluated the ecological range of each species as a criterion, and subsequently, we referred each evaluated taxon to an EU habitat category. The method promotes the free circulation and sharing of scientific information and expands its use by the public. Updating is assured and constant because the database can be not only consulted, but also continuously updated on the basis of new field researches, and as a result of *in situ*

and *ex situ* conservation programmes. The prioritization of plant endemic species and habitats presented in this study is in accordance with the 15 characteristics that should be possessed by systems used for categorizing endangered species (de Grammont & Cuarón 2006).

The method herein proposed is not in contrast to, but complementary with, the application of IUCN criteria. In fact, even if IUCN protocols are widely used to classify the conservation status of all the species in the world, those protocols are useful for forecasting extinctions, but they contain sources of uncertainty (Akçakaya et al. 2000), and are prone to some errors that have enormous implications for conservation (Keith et al. 2004). Adequate solutions that combine the appropriate application of the IUCN criteria with reasonable budgets and research efforts are urgently needed (Joseph et al. 2006; Rodríguez et al. 2007) to answer practical requirements (Eaton et al. 2005) such as assessing priorities among the species that should be included in *ex situ* (Farnsworth et al. 2006; Jiménez-Alfaro et al. 2010)

and *in situ* conservation programmes. IUCN criteria are considered the most objective approach for evaluating the conservation status of taxonomic units (Lamoreux et al. 2003; de Grammont & Cuarón 2006; Rodrigues et al. 2006; Miller et al. 2007; Abeli et al. 2009), and have been developed as instruments that help to organize the conservation of biodiversity at the global level. On the other hand, our method combines the need to have a quick and low-cost assessment procedure, which is, at the same time, as strict, clear and repeatable as possible, also at the local level.

The integrated approach adopted in this study is a concrete solution that adapts IUCN criteria and categories to local contexts (Dunn et al. 1999; Keller & Bollmann 2004) by emphasizing the global biogeographical classification (Takhtajan 1986; Rivas-Martínez 2007; Medina-Cazorla et al. 2010). This method focuses on a local context, whose spatial target is the biogeographical province, rather than considering administrative boundaries (Gauthier et al. 2010). Since it has a wide applicability, the quantitative assessment procedure presented here contributes towards developing a general method once it will be tested in other biodiversity hotspots. In fact, in every part of the world, it is possible to determine, on the basis of biogeographical classifications, whether a species is exclusive to a province, subprovince, sector or district. This approach could be useful especially, but not exclusively, in areas with many insular systems (Martin 2009), for instance, in the following 11 out of the 25 biodiversity hotspots (Myers et al. 2000): Caribbean, Madagascar, Mediterranean Basin, Cape Floristic Province, Sri Lanka, Sundaland, Wallacea, Philippines, New Caledonia, New Zealand, Polynesia/Micronesia. Further studies will be necessary to validate this new method in the global context. The data gathered in this study can be considered as a point of departure for future studies.

This approach guarantees the net distinction between rarity and threats, thereby avoiding the species that are naturally rare, but not threatened, from having the same conservation priority as those that are rare because of a rapid decline caused by anthropogenic or natural threats. As a major outcome of the proposed method, species with highest conservation priority can be considered as those simultaneously geographically restricted and subjected to heavy natural and/or anthropogenic threats. Numerous rare species are found living in selective habitats that require increased levels of ecological specialization, such as cliffs (Larson et al. 2000; Kuntz & Larson 2006; Bacchetta et al. 2007). This result is in accordance with the previous ecological assessments of Mediterranean endemic plants (Thompson et al. 2005).

Although 42.3% of the evaluated endemic plants live on cliffs (habitat categories 1 and 8), the greatest value of PI was found for the coastal dunes (habitat 2), which is at present exposed to great levels of anthropogenic disturbances (including destruction and fragmentation of habitats and extirpation of vegetation). This evidence from Sardinia is in accordance to the findings of Davenport and Davenport (2006), in which the highest levels of human impact were found to affect the plant species and communities living on Mediterranean coastal dunes because of the so-called “sun and sand” tourism (Aguilo et al. 2005).

It is noteworthy that only one (*Anchusa crispa*) out of nine species with an A or B TI is included in Annexe II of the Habitat Directive (European Commission 1992), which has not been updated since 1992. Of the remaining endemic plants included in Annexe II, one (*Centranthus amazonum* Fridl. & A. Raynal) is included in the priority category C1, four [*Centaurea horrida* Badarò, *Herniaria latifolia* Lapeyr. subsp. *litardierei* Gamisans, *Linaria flava* (Poir.) Desf. subsp. *sardoa* (Sommier) Arrigoni and *Silene velutina* Pourr. & Loisel.] in category C2, two (*Astragalus maritimus* Moris and *Limonium pseudolaetum* Arrigoni & Diana) in category D1, and five [*Limonium insulare* (Bég. & Landi) Arrigoni & Diana, *Astragalus verrucosus* Moris, *Limonium strictissimum* (Salzm.) Arrigoni, *Euphrasia genargentea* (Feoli) Diana, and *Linum muelleri* Moris] are found in category D2. The discrepancy between our evaluation and the list of species included in Annexe II of the Habitat Directive suggests that the updating of that Directive is urgent, and that the adoption of a defined, clear, scientific method to assess conservation priorities, also at the European scale, is recommended.

This method of assessment, conceived for plants, also allows the characterization of the EU habitats not only from a quantitative point of view (such as the number of endemic plants living in each habitat), but also and above all from a qualitative point of view (assessing the conservation priority for each habitat). This is a widely applicable method because the need to develop synthetic approaches, to consider specific human impacts, to group species according to both the factors responsible for their rarity and the activities needed for their conservation (Pärtel et al. 2005) is more urgent now than ever. Indeed, species living within the same habitat are likely to have similar biological traits, and to experience similar types of impacts, and, therefore, they require similar conservation and management efforts. In accordance with the European law, each European country or region can define a priority list of species and habitats by using a methodology similar to that described here. Environmental managers, politicians and

decision makers can apply this assessment procedure to several biogeographical contexts for determining conservation priorities among both the species and habitats.

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