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# Biogeographic trends of endemic and subendemic flora in the western Iberian Peninsula under scenarios of future climate change

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**Abstract:** Rocha, J., Almeida da Silva, R., Amich, F., Martins, A., Almeida, P., Aranha, J.T., García-Cabral, I., Martins, M., Castro, C. & Crespí, A.L. *Biogeographic trends of endemic and subendemic flora in the western Iberian Peninsula under scenarios of future climate changes. Lazaroa 35: 19-35 (2014).*

Altitude, temperature and precipitation are important environmental variables for the distribution of endemic plants. Taking in account their present distribution, this work studies the distribution trends of 116 endemic and subendemic species that occur on the western Iberian Peninsula and north-western Morocco, in different scenarios of future climate change. It was possible to identify five groups of taxa in the present environmental conditions, four of which for the northern part of the Iberian Peninsula. This range can partially be explained by the altitudinal variability of such area. The other group distributes along the western of the Iberian Peninsula. Concerning future climate change scenarios, important changes in species distribution, and a general south-north trend were obtained. Under harsher climatic changes, only the groups that tolerate the most variable environmental conditions persist. Estimates of extinction rates of the studied taxa for the next 75 years are also presented. The present methodology allows the application of ecological indicators (environmental groups, in this case) to understand biogeographic trends.

**Keywords:** Species distribution models, environmental variability, Maxent, conservation.

**Resumen:** Rocha, J., Almeida da Silva, R., Amich, F., Martins, A., Almeida, P., Aranha, J.T., García-Cabral, I., Martins, M., Castro, C. & Crespí, A.L. *Tendencias biogeográficas de flora endémica y subendémica en el oeste de la Península Ibérica bajo escenarios de cambio climático futuro. Lazaroa 35: 19-35 (2014).*

Altitud, temperatura y precipitación son variables ambientales importantes en la circunscripción de las distribuciones biogeográficas de plantas endémicas. Tomando en cuenta su distribución actual, este trabajo estudia las tendencias de distribución de 116 especies endémicas y subendémicas que se producen en el oeste de la Península Ibérica y el noroeste de Marruecos, en diferentes escenarios de cambio climático futuro. Se identificaron cinco grupos de taxones en las actuales condiciones ambientales, de las cuales cuatro son para el norte de la Península Ibérica. Este rango se puede explicar parcialmente por la variabilidad altitudinal de dicha zona. El otro grupo se distribuye a lo largo del oeste de la Península Ibérica. En cuanto a los futuros escenarios de cambio climático, se obtuvieron cambios importantes en la distribución de las especies, y una tendencia general sur-norte. Bajo los cambios climáticos más severos, sólo los grupos que toleran las condiciones de la mayoría de las variables ambientales persisten. También se presentan estimaciones de las tasas de extinción de los taxones estudiados para los próximos 75 años. La presente metodología permite la aplicación de los indicadores ecológicos (grupos ecológicos, en este caso) para comprender las tendencias biogeográficcas.

**Palabras clave:** modelos de distribución de especies, variabilidad medioambiental, Maxent, conservación.

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## INTRODUCTION

Biogeographic behaviours of several genera and species have been previously reported for the Iberian Peninsula (OLALDE & *al*., 2002; PETIT & *al*., 2002; VARGAS, 2003; MEJÍAS & *al*., 2007; PARDO & *al*., 2008; GUZMÁN & VARGAS, 2009; CRESPÍ & *al*., 2007; ROCHA & *al*., 2012a; ROCHA & *al*., 2012b; ALMEIDA DA SILVA & *al*., 2014). Based on these descriptions, two distinct dynamics were identified for the western Iberian Peninsula: one along the northern mountains system, and another closer to the southern coast. Endemic and non-endemic *taxa*, have been used in these biogeographic descriptions. Yet, endemic *taxa* are much more reliable descriptors of such dynamics. In this sense, the hypothesis of centres of endemicity being areas of special evolutionary history, brings important implications for biogeographic performances (JETZ & *al*., 2004). The most obvious refers to bioenvironmental restrictions, saying that endemic species with restricted distributions will also respond to limited environmental amplitudes (KRUCKEBERG & RABINOWITZ, 1985). In this context, arises the question: could the environmental characterizations of those areas be a proper approach to explain the biogeographic dynamics at a regional scale? Accepting the hypothesis aforementioned the mapping of areas of intense evolutionary activity, can well translate endemic biogeographic trends, and can be extremely useful to describe recent floristic dynamics at a regional level (YOUNG & *al*., 2002; CALSBEEK & *al*., 2003; HOPPER & GIOIA, 2004).

The floristic distribution through the western Iberian Peninsula has been studied and analysed by several authors for different species or genera (TABERLET & *al*., 1998; HEWITT, 1999; PETIT & *al*., 2002; PEÑUELAS & BOADA, 2003; MEJÍAS & *al*., 2007; PARDO & *al*., 2008; GUZMÁN & VARGAS, 2009; ROCHA & *al*., 2012a). Conservational concerns (FERRIER & *al*., 2002; ENGLER & *al*., 2004; THUILLER & *al*., 2005; RODRÍGUEZ & *al*., 2007; BENITO & *al*., 2009; ROCHA & *al*., 2012b) and *taxa* sensitivity to climate change (WOHLGEMUTH 1998; GUISAN & THEURILLAT, 2000; SANZ-ELORZA, 2003; ELITH & *al*., 2006; HARRISON & *al*., 2006; BENITO GARZÓN & *al*. 2007; HERNÁNDEZ-SANTANA & *al*., 2008; RUIZ-LABOURDETTE & *al*., 2012) were the main reasons for preferentially using endemic species in these contributions.

Based on the higher sensibility of endemic *taxa* to environmental changes, an approach to future dynamic flows of this flora under climate change scenarios is here proposed. A set of endemic *taxa* with different life forms and known biogeographic distributions (and thus different sensitivities to climate change) were selected. The general requirement was their Iberian endemicity (some included *taxa* also occur in the south-western France and in north-western Morocco).

A Species Distribution Model (SDM) was applied to describe the spatial relationship between the species and their overall environmental variability in the geographic area (GUISAN & THUILLER, 2005; ELITH & LEATHWICK, 2009). After the environmental characterization of these endemisms, grouped environmentally, a forecasting analysis was developed under two predicted future scenarios of climate change, would allow a dynamic picture of these environmental groups of species to be obtained. The results achieved will be a contribution to describe the biogeographic floristic dynamics of the flora of the western Iberian Peninsula. At the same time, they will also be useful to consolidate the management conservation policies for rare or more restricted flora in western Iberian Peninsula.

## MATERIAL AND METHODS

### STUDY AREA AND DATA COLLECTION

The criterion used to limit the study area, was based on the general geomorphology of the Iberian Peninsula according to RIVAS-MARTINEZ (1987) and RIVAS-MARTINEZ & RIVAS-SÁENZ (2009), the Carpetan-Iberian-Leonese province has a natural border that separates the north from the south by the Central Mountains System. The southern area was defined by the Gado-Algarvian province.

The study area was refined taking in account the capacity for grouping *taxa* and the speciation described for the south-western side of the Iberian Peninsula and north-western Morocco. This effect was already pointed out by several authors for other *taxa* (PARDO & *al.*, 2008; GUZMÁN & VARGAS, 2009; ROCHA & *al.*, 2012a; ALMEIDA DA SILVA & *al.*, 2014). A western biogeographic dynamics, limited by the biological Almerian and Iberian System border (HERNÁNDEZ BERMEJO & SAÍNZ OLLERO, 1984), could explain the expansion of the floristic cast along the western part of Europe, from the Tanger-Cadiz-Algarve bay.

In order to obtain a significant resolution of the potential areas and their modelling (AUSTIN, 2007), it was used a species selection system that would allow to maintain the balance between the north and south quadrants, based on general and regional floras (AMARAL FRANCO, 1971, 1984; AMARAL FRANCO & ROCHA AFONSO, 1994, 1998, 2003; http://www.floraiberica.es; VALDÉS & *al.*, 1987; BLANCA & *al.*, 2011).

Although there is no clear relation between threatened species and the fact a species being endemic (according IUCN criteria, 2012), to obtain the final list of *taxa* included in this work, the official threatened plant lists published for the Spanish - communities of Asturias, Castilla-León, Extremadura and Andalusia (http://www.conservacionvegetal.org/legislacion.php?id_categoria=8) - were consulted. For Portugal, there is still no list of threatened species officially published (with the exception of the ones included in the Directive 92/43/CEE). Some unpublished data of field prospections, was also analysed.

With this information, 116 taxa were selected (see Table 1), based on three main criteria: a) species with a preferential distribution in the selected area; b) proportionality in the distribution along this area should be maintained (a similar number of species in its middle northern and southern part); and c) diversity of life forms.

To map their distributions occurrences were geo-referenced using a 1 $km^2$ grid resolution (according to the pixel resolution of the environmental variables data), as recommended by GUTIÉRREZ & PONS (2006).

The locations of the species in the field, were obtained from several herbaria (67% of the gathered information) possessing data form specimens of the Western Iberian Peninsula (BRESA, COI, HVR, LEB, LISE, LISI, LISU, MA, PO, SALA - http://sweetgum.nybg.org/ih/ihmapsearch.php-). Complementary information was taken from field expeditions and the Anthos database (http://www.anthos.es) for areas without other available references. The life forms classification was carried out using Raunkier´s tipification, adapted from BRAUN-BLANQUET (1979).

### ENVIRONMENTAL CHARACTERIZATION AND POTENTIAL DISTRIBUTIONS

Based on the occurrence of the species, an environmental assesment was made, using 68 environmental variables found in WORLDCLIM (http://www.worldclim.org/formats), and the thermic and pluviometric WORLDCLIM application for their analysis (http://www.worldclim.org/).

The achieved environmental matrix, in which the thermic, pluviometric and altitudinal information was specified for each location, was also applied for similar characterizations (ROCHA & *al.*, 2012a; ROCHA & *al.*, 2012b; ALMEIDA DA SILVA & *al.*, 2014). A similarity analysis (Unweight Pair Group Average -UPGA- amalgamation and Manhattan City-block distances) was applied to establish environmentally similar groups. The obtained groups of species, were characterized statistically by multivariate analysis, after a previous standardization of the environmental matrix. These groups were decisive for describing the biogeographic behaviour of the selected *taxa*.

The most discriminating environmental variables were obtained by Discriminate Canonical Analysis (DCA), and its numerical parameters: the F statistic (F-remove) and p-levels to describe the distribution of the variable, Wilk´s Lambda as the test to explain variance between variables, and tolerance (in this case, the squared multiple correlation). Finally, the representation of ranges by environmental variables and group of species, was represented by mean ± standard deviation/mean ± 1.96 standard deviation plots. The STATISTICA v. 9.1 software was applied for these analyses and graphic representations.

Table 1
List of analyzed species, their general distributions in the study area (Dist: northern, N; southern, S), life forms (according to Raunkier classification), and environmental group where they were included.

| Species | Dist | Life forms | Environ. Group |
|---|---|---|---|
| *Aconitum napellus* subsp. *castellanum* | C | Geophyte | 1C |
| *Adenocarpus argyrophyllus* | C | Microphanerophyte | 1C |
| *Adenocarpus telonensis* | S | Nanophanerophyte | 2 |
| *Allium schmitzii* | NS | Helophyte | 2 |
| *Allium victorialis* | N | Geophyte | 1C |
| *Anarrhinum duriminium* | N | Chamaephyte | 2 |
| *Anarrhinum longipedicellatum* | N | Hemicriptophyte | 1A |
| *Anthemis alpestris* | N | Chamaephyte | 1C |
| *Antirrhinum cirrhigerum* | S | Chamaephyte | 2 |
| *Antirrhinum linkianum* | NS | Chamaephyte | 2 |
| *Anthyllis vulneraria* subsp. *iberica* | N | Chamaephyte | 1A |
| *Anthyllis vulneraria* subsp. *sampaiana* | NS | Chamaephyte | 2 |
| *Arabis juresii* | N | Hemicriptophyte | 1C |
| *Arenaria querioides* | N | Terophyte | 1C |
| *Armeria humilis* subsp. *humilis* | N | Chamaephyte | 1B |
| *Armeria humilis* subsp. *odorata* | N | Chamaephyte | 1B |
| *Armeria linkiana* | S | Hemicriptophyte | 20 |
| *Armeria velutina* | S | Chamaephyte | 2 |
| *Aster aragonensis* | N | Hemicriptophyte | 1C |
| *Bufonia macropetala* | NS | Chamaephyte | 1C |
| *Calendula suffruticosa* subsp. *lusitanica* | NS | Chamaephyte | 2 |
| *Calicotome villosa* | S | Nanophanerophyte | 2 |
| *Carex asturica* | N | Geophyte | 1B |
| *Cistus libanotis* | S | Nanophanerophyte | 2 |
| *Cytisus arboreus* subsp. *baeticus* | S | Microphanerophyte | 2 |
| *Cytisus grandiflorus* subsp. *cabezudoi* | S | Nanophanerophyte | 2 |
| *Dianthus langeanus* | N | Chamaephyte | 1C |
| *Digitalis purpurea* subsp. *amandiana* | N | Hemicryptophyte | 2 |
| *Diplotaxis siifolia* subsp. *vicentina* | S | Terophyte | 2 |
| *Drosophyllum lusitanicum* | NS | Geophyte | 2 |
| *Echinospartum ibericum* | N | Nanophanerophyte | 1C |
| *Elaeoselinum foetidum* | S | Hemicryptophyte | 2 |
| *Erica lusitanica* | NS | Nanophanerophyte | 2 |
| *Erophaca baetica* | NS | Hemicryptophyte | 2 |
| *Erysimum merxmuelleri* | S | Chamaephyte | 1C |
| *Euphorbia polygalifolia* subsp. *polygalifolia* | N | Chamaephyte | 1C |
| *Euphorbia uliginosa* | N | Chamaephyte | 2 |
| *Festuca duriotagana* | NS | Hemicryptophyte | 2 |
| *Festuca summilusitana* | N | Hemicriptophyte | 1B |
| *Galega cirujanoi* | C | Hemicriptophyte | 2 |
| *Galium glaucum* subsp. *australis* | N | Hemicriptophyte | 2 |
| *Genista ancistrocarpa* | N | Nanophanerophyte | 2 |
| *Genista berberidea* | N | Nanophanerophyte | 1A |
| *Genista carpetana* | N | Chamaephyte | 1C |
| *Genista hystrix* | N | Nanophanerophyte | 1C |
| *Genista micrantha* | N | Chamaephyte | 1C |
| *Genista polyanthos* | S | Nanophanerophyte | 2 |
| *Genista sanabrensis* | N | Nanophanerophyte | 3 |
| *Genista tournefortii* | NS | Chamaephyte | 1C |
| *Genista triacanthos* | NS | Nanophanerophyte | 2 |

| Species | Dist | Life forms | Environ. Group |
|---|---|---|---|
| *Halimium calycinum* | S | Chamaephyte | 2 |
| *Halimium umbellatum* subsp. *umbellatum* | N | Chamaephyte | 1C |
| *Holcus annus* subsp. *duriensis* | N | Terophyte | 2 |
| *Holcus gayanus* | N | Terophyte | 1C |
| *Hyacinthoides mauritanica* | S | Geophyte | 2 |
| *Hymenostemma pseudanthemis* | S | Terophyte | 2 |
| *Iberis procumbens* subsp. *procumbens* | S | Chamaephyte | 2 |
| *Jasione cavanillesii* | N | Chamaephyte | 3 |
| *Jasione crispa* subsp. *mariana* | C | Chamaephyte | 2 |
| *Juncus emmanuelis* | S | Helophyte | 2 |
| *Lavandula viridis* | S | Chamaephyte | 2 |
| *Limonium algarvense* | S | Hemicryptophyte | 2 |
| *Limonium ovalifolium* | S | Chamaephyte | 2 |
| *Loeflingia baetica* | S | Terophyte | 2 |
| *Malva hispanica* | S | Chamaephyte | 2 |
| *Marsilea batardae* | S | Helophyte | 2 |
| *Mercurialis reverchonii* | S | Chamaephyte | 2 |
| *Narcissus asturiensis* | N | Geophyte | 1B |
| *Nothobartsia asperrima* | NS | Chamaephyte | 2 |
| *Ononis broteriana* | NS | Terophyte | 2 |
| *Ononis cintrana* | S | Terophyte | 2 |
| *Otospermum glabrum* | S | Terophyte | 2 |
| *Paradisea lusitanica* | N | Geophyte | 1C |
| *Pistorinia hispanica* | NS | Terophyte | 1C |
| *Plantago monosperma* subsp. *discolor* | N | Chamaephyte | 1C |
| *Polygala baetica* | S | Chamaephyte | 2 |
| *Rhododendrum ponticum* subsp. *baeticum* | NS | Microphanerophyte | 2 |
| *Rhynchospora modesti-lucennoi* | S | Chamaephyte | 2 |
| *Santolina semidentata* | N | Chamaephyte | 1C |
| *Scrophularia sambucifolia* | S | Hemicriptophyte | 2 |
| *Scrophularia sublyrata* | NS | Hemicriptophyte | 2 |
| *Selinum broteri* | N | Hemicriptophyte | 1C |
| *Sempervivum vicentei* | N | Chamaephyte | 3 |
| *Sideritis arborescens* | S | Chamaephyte | 2 |
| *Sideritis lurida* | NS | Chamaephyte | 1C |
| *Silene acutifolia* | N | Hemicriptophyte | 1B |
| *Silene coutinhoi* | N | Hemicriptophyte | 2 |
| *Silene longicilia* | NS | Hemicriptophyte | 2 |
| *Silene mariana* | S | Terophyte | 2 |
| *Silene marizii* | N | Hemicriptophyte | 1C |
| *Spergula viscosa* | N | Chamaephyte | 3 |
| *Stauracanthus genistoides* | S | Nanophanerophyte | 2 |
| *Succisella microcephala* | C | Chamaephyte | 1C |
| *Teucrium algarbiense* | S | Chamaephyte | 2 |
| *Teucrium salviastrum* | N | Chamaephyte | 1B |
| *Thapsia minor* | NS | Hemicriptophyte | 2 |
| *Thapsia nitida* | S | Hemicriptophyte | 2 |
| *Thapsia transtagana* | S | Hemicriptophyte | 2 |
| *Thymelaea broteriana* | N | Chamaephyte | 1C |
| *Thymelaea lanuginosa* | S | Nanophanerophyte | 2 |
| *Thymus albicans* | S | Chamaephyte | 2 |
| *Thymus carnosus* | S | Chamaephyte | 2 |
| *Thymus villosus* subsp. *lusitanicus* | S | Chamaephyte | 2 |
| *Thymus zygis* subsp. *sylvestris* | S | Chamaephyte | 2 |

| Species | Dist | Life forms | Environ. Group |
|---|---|---|---|
| *Thymus villosus* subsp. *villosus* | S | Chamaephyte | 2 |
| *Thymus zygis* subsp. *zygis* | N | Chamaephyte | 1C |
| *Ulex argenteus* | S | Nanophanerophyte | 2 |
| *Ulex erinacenus* | S | Chamaephyte | 2 |
| *Ulex micranthus* | N | Nanophanerophyte | 1A |
| *Verbascum barnadesii* | S | Hemicriptophyte | 2 |
| *Verbascum litigiosum* | S | Hemicriptophyte | 2 |
| *Verbascum giganteum* subsp. *martinezii* | S | Hemicriptophyte | 2 |
| *Veronica mampodrensis* | N | Chamaephyte | 3 |
| *Veronica micrantha* | N | Chamaephyte | 1C |
| *Viola langeana* | N | Hemicriptophyte | 1C |
| *Xolantha globulariifolia* | N | Hemicriptophyte | 1C |

The potential habitat distribution areas and previsions for environmental groups and subgroups, were obtained with the MAXENT software, v. 3.3.3e (http://www.cs.princeton.edu/~schapire/maxent/). MAXENT estimates the distribution probability of a species occurrence, based on environmental constraints (PHILLIPS & *al*., 2006). It only requires the data of the species presence, and the environmental variables in GIS layers, for the study area. The MAXENT software was used to estimate the probability of a potentially suitable habitat for species occurrence, varying from 0 to 1, where 0 is the lowest and 1 the highest probability.

The modelling approach was validated based on the probability that locations with a confirmed presence of the species, ranked higher than a random background probability, also with a characteristic receiver-operating (ROC) plot (FIELDING & BELL 1997), and an area under the curve (AUC) approach (PHILLIPS & *al*. 2006). Locations with a random background probability served as pseudo-absences for all analyses in MAXENT (PHILLIPS & *al*., 2004; PHILLIPS & *al*., 2006).

The MAXENT jack-knife approach was used for assessing the importance of the variable (YOST & *al*., 2008). The training gain was calculated for each variable as well as the drop in training gain when the variable was omitted from the full model (PHILLIPS & *al*., 2006).

For all models, the following parameters were used: 10 repetitions with cross-validation, standard regularization multiplier (affects how focused or closely-fitted the output distribution is), 500 iterations (for further details on these parameters, see PHILLIPS (2010) and a threeshold of 0.5, meaning that only suitable habitat areas ranking higher than 0.5 of probability of occurrence were chosen - to describe the most significant distribution areas. The output obtained (in ASCII format) was then used as input for a GIS project (ArcGIS software version 9.2 - ESRI, Redlands, California, USA) as a floating-point grid (PETERSON & *al*. 2007), revealing the probability of the occurrence of the species at each site and resulting in a continuous map.

## MODELLING THE POTENTIAL FUTURE DISTRIBUTIONS

The climate predictors were derived from a general circulation model (CCCMA: CGCM2) for 2080, under the IPCC emission scenarios (SRES; A2a and B2a) for predicting future potential distribution areas (http://gisweb.ciat.cgiar.org/GCMPage; RAMÍREZ & JARVIS, 2008). The scenarios A2a and B2a represent two different possible situations of greenhouse gas emissions. In comparison with A2a, B2a has a lower rate of global warming, and hence changes in temperature and precipitation are less intense (http://forest.jrc.ec.europa.eu/climate-change/future-trends).

In order to confirm the previsions per environmental group, potential distribution areas and previsions for both future scenarios were also elaborated for each species individually. This approach was necessary to confirm the result obtained for every environmental group, based on the variability of information included in each group.

## RESULTS

### ENVIRONMENTAL CHARACTERIZATION AND POTENTIAL DISTRIBUTIONS

The map detailing the present known distribution of *taxa* is shown in Figure 1 (for 2983 confirmed locations). A total 40% of the studied species were concentrated in the north, 40% in the south, 4% just in the center, and the remaining 16% along the area.

The similarity analysis on the environmental matrix is shown in the dendrogram of Figure 2a. Three basic groups were primarily observed: groups 1, 2 and 3. The first one is subdivided in three subgroups: group 1a, 1b, and 1c. This classification is deduced according to the CDA for the environmental matrix, for the most discriminant classification (the highest F, highest Wilks´ lambda, and lowest p-value) deduced from the dendrogram obtained from the similarity analysis. The CDA for the environmental matrix classified into five environmental groups (included here the three subdivisions of group 1) is graphically represented in Figure 2b. Altitude (F=11.857, p-level<0.001) and precipitation seasonality (bio 05, F=10.350, p-level<0.001) are the most discriminant environmental variables to distinguish those five groups (Table 2). This last environmental variable describes the variability of average precipitation among seasons along the year (coefficient of variation between seasons).

The potential distribution map for the environmental groups is exposed in Figure 3. The concentration of habitats suitable for harbouring the environmental groups is clearly different for group 1 and 2, but regionally overlapped in the north-eastern. The potential environmental distribution for group 1 (subgroups 1a, 1b and 1c) is concentrated in the northern of the area, for group 2 is extended along the whole area (at low altitude). The potential occurrence of group 3 is also located in the northern area, but at the highest altitudes of the Cantabrian mountain system.

In the case of group 1, the three potential distributions of subgroups 1a, 1b and 1c are evidently distinguished. Potential occurrence for subgroup 1a is along the coast and at low altitudes of north-western and north; subgroup 1b is restricted to the occident of the lusitanian-gallaecian mountain system; and subgroup 1c is more concentrated in the most continental side of the north-western and northern of the area.

The life form description of each environmental group and subgroup is exposed in Table 3. In

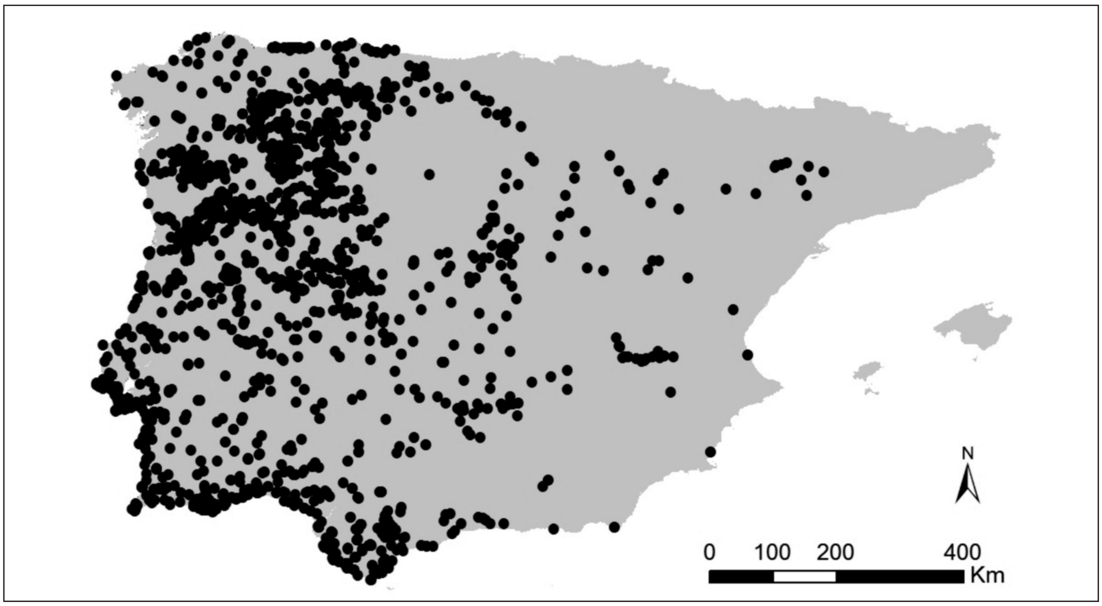


Figure 1. – Distribution maps of populations occurrences for all the species analysed.

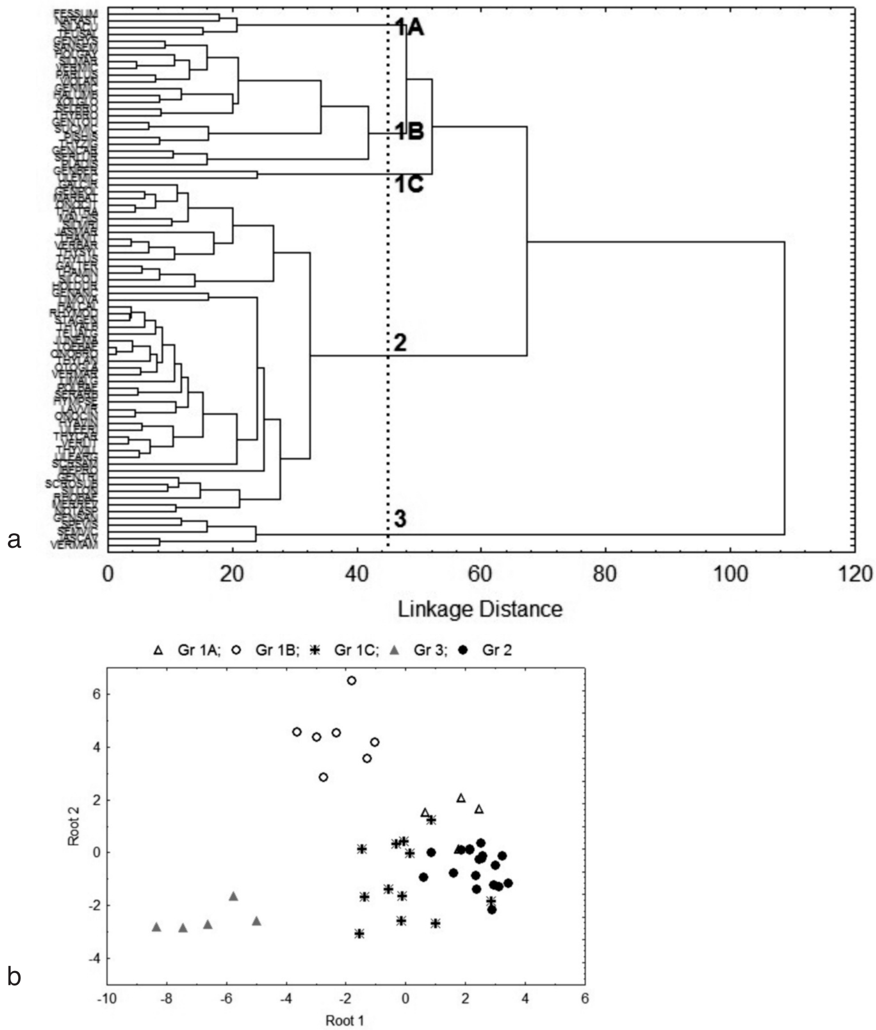


Figure 2. – Multivariate analysis of the environmental matrix: (a) dendrogram obtained from the similarity analysis of average environmental variables per taxon, with groups (Gr.) and subgroups (Sgr.) represented, and their maps of current potential distribution; (b) graphic representation of DCA for the five groups (1 -1a, 1b, and 1c-, 2 and 3).

Table 2
Numerical values of CDA for the environmental matrix. Altitude (F=11.857, p-level<0.001) and precipitation seasonality (bio 5, F=10.350, p-level<0.001) are the most discriminant environmental variables.

| | Wilks' Lambda | F-remove (4,51) | p-level | Toler. |
|---|---|---|---|---|
| altitude | 0,030243 | 10,21554 | 0,000004 | 0,409161 |
| prec4 | 0,026711 | 7,53363 | 0,000076 | 0,099515 |
| prec1 | 0,028414 | 8,82649 | 0,000017 | 0,066694 |
| bio 5 | 0,030666 | 10,53671 | 0,000003 | 0,159397 |
| tmin7 | 0,024746 | 6,04113 | 0,000466 | 0,186567 |

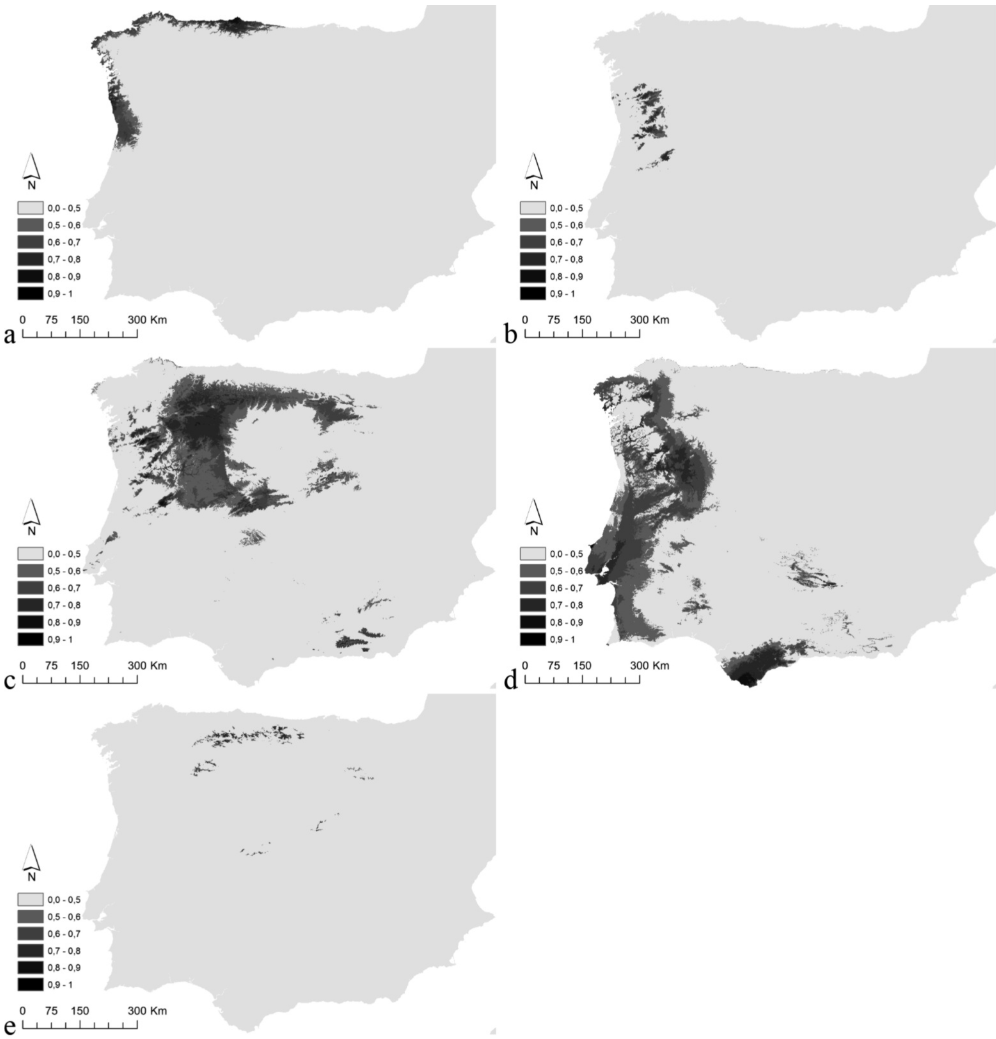


Figure 3. – Potential distribution areas for the bioclimatic groups: a) group 1a, b) group 1b, c) group 1c, d) group 2, and e) group 3. All these bioclimatic groups are represented for the middle northern of the study area, in contrast with the middle southern where just group 2 occurs.

terms of life forms, 9% were therophytes, 23% hemicryptophytes, 6% geophytes, 42% chamaephytes, 14% nanophanerophytes, 3% microphanerophytes, and 3% helophytes.

Group 2 and subgroup 1c are the most diverse in terms of life forms. In contrast, the rest of the environmental groups are extremely restricted: biannual (hemicriptophytes) or perennial herbaceous (geophytes and chamaephytes), or small shrubs (nanophanerophytes) are the only forms observed. These results could be associated with the environmental variability obtained for groups 2 and 1c, both of them very similar about their altitudinal ranges (Figure 4).

### Modelling the potential future distributions

Projections of potential distributions for environmental groups 2, for both 2080 scenarios, show an evident shift towards the northern part of the Iberian Peninsula (Figure 5). Groups 3 and

Table 3
Percentages of life forms per environmental group (Tero, terophytes; Hemi, hemicriptophyte; Geop, geophytes; Helo, helophytes; Cham, chamaephytes; Nano, nanopharerophytes; Micr, microphanerophytes).

| | Tero | Hemi | Geop | Helo | Cham | Nano | Micr |
|---|---|---|---|---|---|---|---|
| Group 1a | 0 | 3,7 | 0 | 0 | 2,04 | 12,5 | 0 |
| Group 1b | 0 | 7,41 | 28,57 | 0 | 6,12 | 0 | 0 |
| Group 1c | 27,27 | 22,22 | 42,86 | 0 | 32,65 | 12,5 | 33,33 |
| Group 2 | 72,73 | 66,67 | 28,57 | 100 | 51,02 | 68,75 | 66,67 |
| Group 3 | 0 | 0 | 0 | 0 | 8,16 | 6,25 | 0 |

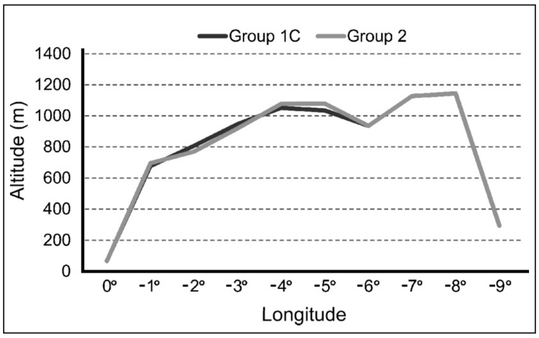


Figure 4. – Average altitude for the 1c and 2 bioclimatic groups from eastern to western of the study area. Both bioclimatic groups show a very similar and wide altitudinal range.

1, with subgroups 1a, 1b, and 1c, reflect significant decreases or even extinctions (group 3 for both scenarios, and subgroup 1b for the A2a scenario) in the potential habitat distributions.

The current thermic and pluviometric characterization per envionmental group is explained in Table 4. Group 3 and subgroups 1a and 1c are clearly cooler than group 2 or subgroup 1b. This circumstance is maintained for the future climatic change scenarios A2a and B2a, where an increasing of 3º-4ºC and a decreasing in 20% for annual precipitation are confirmed for all the environmental groups. These results are in accordance with previous previsions for Mediterranean areas (LOARIE & *al*., 2009).

Table 4
Thermic and pluviometric values for the current situation and for the climate scenarios analysed (A2a and B2a) in 2080, based on the annual average precipitation (P), annual lowest temperature (tmin) and annual highest temperature (tmax), per environmental group.

| | Current | | | 2080 A2a | | | 2080 B2a | | |
|---|---|---|---|---|---|---|---|---|---|
| Groups | P (mm) | tmin (°C) | tmax (°C) | P (mm) | tmin (°C) | tmax (°C) | P (mm) | tmin (°C) | tmax (°C) |
| 1a | 87 | 1 | 11 | 69 | 4 | 15 | 80 | 3 | 14 |
| 1b | 88 | 10 | 18 | 73 | 12 | 21 | 83 | 12 | 20 |
| 1c | 120 | 6 | 15 | 98 | 9 | 18 | 113 | 8 | 17 |
| 3 | 70 | 6 | 16 | 56 | 9 | 20 | 65 | 8 | 19 |
| 2 | 55 | 11 | 21 | 43 | 14 | 24 | 49 | 13 | 23 |

Table 5
Potential areas of the bioclimatic groups (Km2), under the current climatic conditions and for both future climate scenarios (A2 and B2). Surfaces were also calculated based on the species distributions of each group (with *).

| | Group 1a | Group 1b | Group 1c | Group 2 | Group 3 |
|---|---|---|---|---|---|
| Current | 20495 | 7234 | 116460 | 139247 | 4251 |
| 2080 A2a | 2031 | 0 | 9021 | 72502 | 0 |
| 2080 B2a | 16050 | 703 | 50087 | 91485 | 62 |
| 2080 A2a* | 595 | 1321 | 72291 | 76996 | 0 |
| 2080 B2a* | 5245 | 4624 | 86972 | 69256 | 517 |

The surfaces occupied by the groups in the future scenarios are also very explicit (Table 5). Group 3 and subgroup 1b will disappear (A2a) or reduce severally their surfaces (B2a). For the other groups substantial decreases are verified. The largest group (group 2) is the most resistant, keeping extensive areas in both scenarios.

The individual analysis of every species (for the current climatic conditions and for the future scenarios) is also exposed in Table 5. With the exception of groups 1c and 2 -where the areas previewed in both scenarios are much higher than those previewed as a group (subgroup 1c), or with opposite results (group 2)-, the other environmental groups show similar behaviors. The cases of groups 1c and 2 could be explained by their environmental variability. In fact, the potential areas deduced for both, are significantly higher than for the others (1a, 1b and 3). This issue will force the subdivision of groups 1c and 2, in order to obtain a better description for future scenarios.

The significance of the changes observed for the potential distribution per environmental group and subgroup, in both climate change scenarios, analysed by a CDA (Figure 6a-c), shows that the highest average temperature in July (tmax7) exposes the most important variations between the current and the future conditions. These variations are more relevant for the group 3 and the subgroups 1, than for the group 2.

## DISCUSSION

Several authors have discussed an expected northward displacement of the flora in result of future climate changes (HUNTLEY & *al*., 1995; COMES & KADEREIT, 1998; PUIG DE FÁBREGAS & MENDIZABAL, 1998; WALTHER, 2003; JUMP & *al*., 2006a, b; BENITO GARZÓN & *al*., 2008; RODRÍGUEZ SÁNCHEZ & ARROYO, 2008; ROCHA & *al*., 2012b). Several modelling approaches have been elaborated, with different ecological and geographic ranges for species (GUISAN & THEURILLAT, 2000; al. & *al*., 2003; ENGLER & *al*., 2004; RANDIN & *al*., 2006; RUIZ-LABOURDETTE & *al*., 2012). Yet, all the mentioned cases, the modelling was applied individually by taxon, and not to sets of *taxa*. However, contributions using groups of species with similar ecological amplitudes (TER-BRAAK & GREMMEN, 1987) or sets of endemic species with different life forms (BROENNIMANN & *al*., 2006), have reported promising results.

Three different types of behaviours were found: two of them are represented by potential distributions on the northern (groups 1 and 3), and one along the analysed area (group 2). In group 1, three behaviours are distinguished for the northern potential habitats of the group 1, one of them is restricted to potential habitats along the coast (subgroup 1a), a second one for the most occidental mountains (subgroup 1b), and the third group describes dryer and continental potential habitats (subgroup 1c).

Traditionally, the areas where the studied species are concentrated (both in the north and in the southern biogeographic area) have been referred as biological refugia (MÉDAIL & QUEZEL, 1997; MORENO SAÍZ & SAÍNZ OLLERO, 1997; MORENO SAÍZ & *al*., 1998; LOBO & *al*., 2001; GIMÉNEZ & *al*., 2004).

These results help to understand the gene flow proposed by several authors for the western Iberian Peninsula (TABERLET & *al*., 1998; OLALDE & *al*., 2002; PETIT & *al*., 2002; VARGAS, 2003; MEJÍAS & *al*., 2007; PARDO & *al*., 2008; GUZMÁN & VARGAS, 2009; ROCHA & *al*., 2012a), and to explain the significant geographic environmental connectivity along the western of the Iberian Peninsula (group 2 and subgroup 1c). The high concentration of endemic species in northwestern Iberian Peninsula is explained by the presence of distinct potential habitats for mountains (group 3 and subgroup 1b) and north coast (subgroup 1a). On the contrary the high environmental variability for groups 1c and 2 with significant divergences between grouping and specific predictions will demand more subdivisons. Additionally, the rapid response of all the environmental groups to climate changes indicates an extremely thermic and pluviometric dynamic. This rapid response could reflect a very active gene flow, possibly as a result of the characteristic intense climatic variability prevailing since the late Pliocene (OLDFIELD, 2005; TZEDAKIS, 2007). These relevant changes have

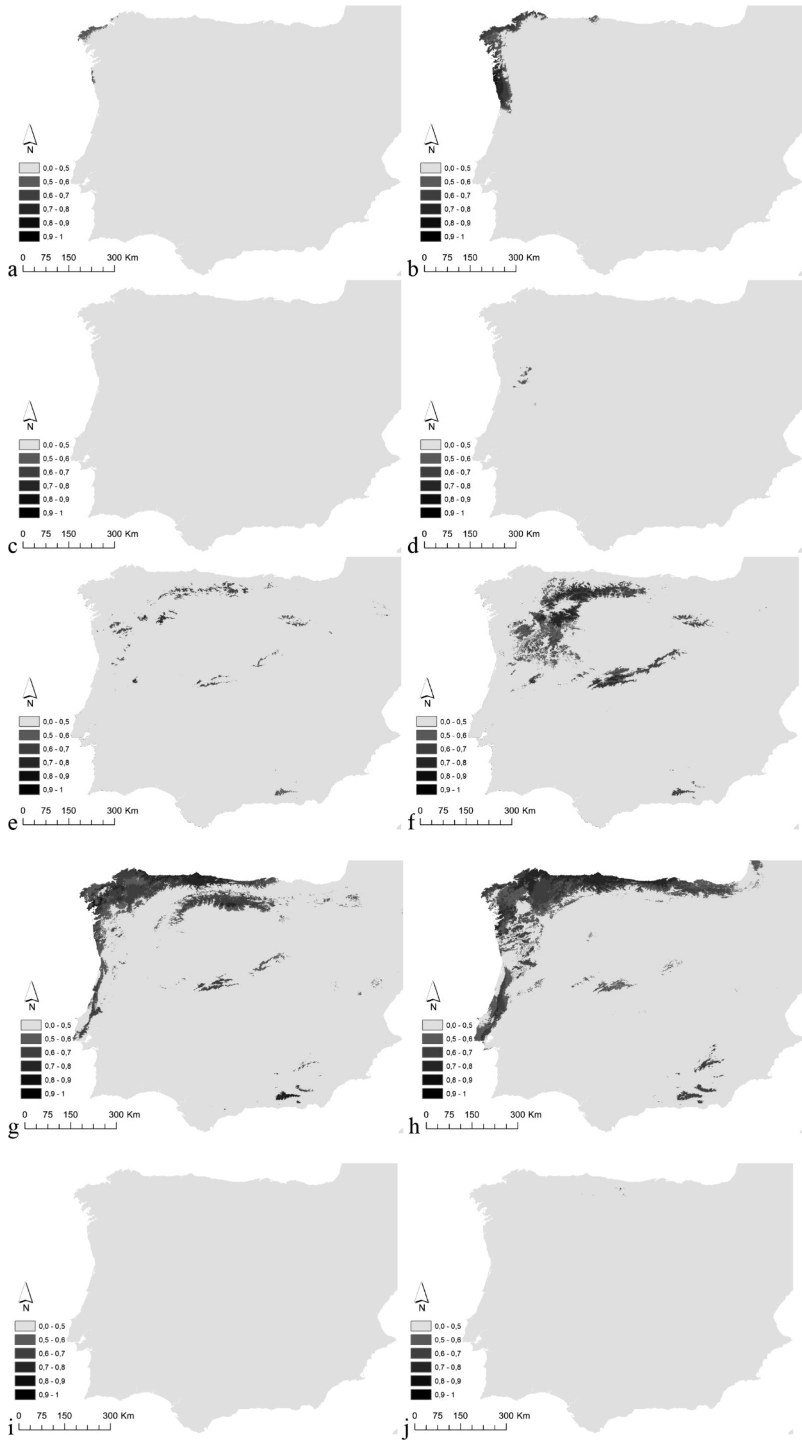


Figure 5. – Bioclimatic groups areas under the effect of future climate change scenarios A2 and B2 in 2080: a) group 1A for A2 scenario; b) group 1a for B2 scenario; c) group 1b for A2 scenario; d) group 1b for B2 scenario; e) group 1c for A2 scenario; f) group 1c for B2 scenario; g) group 2 for A2 scenario; h) group 2 for B2 scenario; i) group 3 for A2 scenario; j) group 3 for B2 scenario.

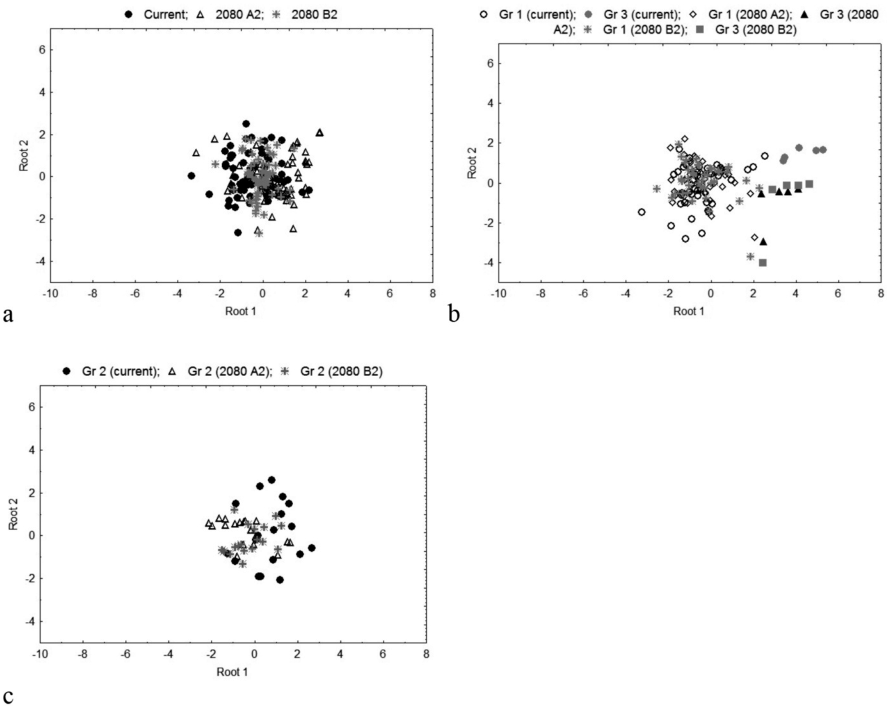


Figure 6. – CDA graphic representation for the first two roots, a) for current and future climate change scenarios for the five bioclimatic groups; b) for group 1 (1a, 1b and 1c) and group 3; and c) for group 2.

determined the migration of individuals across western Europe (HEWITT, 1996; TABERLET & *al*., 1998). Advances and setbacks, the access to different altitudinal levels, and the contact between different types of biogeographic behavior have been the main consequences of this intensive biogeographic dynamic (GUTIÉRREZ LARENA & *al*., 2002; HEWITT, 2004; FRAJMAN & OXELMAN, 2007; MÉDAIL & DIADEMA, 2009). In this sense, the peninsular geomorphological variability has acted as an extremely important distributing regulator in this biological process (SWANSON & *al*., 1988; STALLINS, 2006). This dynamic biological and environmental correlation is now involved in the refugee discussion (MÉDAIL & DIADEMA, 2009; GÓMEZ & LUNT, 2007; NIETO FELINER, 2011, 2014). The lack of thermic and pluviometric stability introduces the possibility of dynamic refugia, in contrast with the static idea of environmental areas where species will find their potential habitat. In accordance with this discussion, the endemic species especially those with more restricted ecological amplitudes, will be biological indicators of this process.

The results obtained for future climatic change scenarios show alarming thermic and pluviometric forecasts for the preservation of species. Special attention must be considered for the mountain groups (group 3 and subgroup 1b), and north Atlantic potential habitats, seriously threaten. Results such as those discussed here draw attention to the importance of monitoring policies, to guarantee the preservation of the species with occurrence in the most sensitive environmental groups and subgroups.

In the present work the groups, obtained by similarity of thermic, pluviometric and altitudinal amplitudes of endemic and restricted subendemic species contribute to describe the biogeographic floristic dynamics of the flora of the western Iberian Peninsula. To know the geographic dynamic of these environmental groups under future climate changes, will also be very useful for conservation purposes, or even to understand and explain quaternary phylogenetic routes (COMES & KADEREIT, 1998; TABERLET & *al*., 1998; OLALDE & *al*., 2002; VARGAS, 2003).

## CONCLUSIONS

The diversity of environmental groups and subgroups, which are significantly different on the western Iberian Peninsula, reflects the potential habitat complexity of this region. Anyway, the continuity along these environmental clusters of potential habitats along the study area is guaranteed by the groups and subgroups detected. In this sense, restricted and broader environmental amplitudes are obtained for these environmental subgroups.

A very dynamic biogeographic behavior is deduced by these environmental groups and subgroups when exposed to future climate changes scenarios. A trend to north of the area, as well as important transformations in the potential habitat areas and the elimination of some of them, are the most relevant consequences of this forecast. These results allowed to understand the recent gene flow across this area described by several authors, but at the same time the environmental groups here described seem useful biological indicators for recent biogeographic trends in western Iberian Peninsula.

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