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An environmental land classification of Spain.

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Abstract

The complex pattern and relationships of Spanish natural environments are revealed by a land classification that is constructed using a statistical procedure for identifying similar environmental areas, regardless of their geographic location across the country. Rather than treating all environments as equally different, the dissimilarity between them is also quantified. This classification is based on a comprehensive set of variables that strongly influence geographic variation in biotic patterns. The resolution is 1 km^2. The resulting 90 strata (68 in Iberian-Balearic Spain, 22 in the Canary Islands) can be aggregated hierarchically depending on the level of generalization that is required.

Although it was primarily constructed as a spatial reference framework for the development of the Natura 2000 network, this classification was conceived as a nationally consistent tool for monitoring, reporting and management of a range of issues, including biodiversity and land uses.

Key words: Clustering, Ecological land classification, Environmental gradient, Environmental stratification, Hierarchical classification.

Riassunto

Il modello complesso e le relazioni degli ambienti naturali spagnoli sono evidenziate da una classificazione del territorio che è stata costruita utilizzando una procedura statistica per identificare le aree ambientali simili, indipendentemente dalla loro posizione geografica in tutto il paese. Piuttosto che trattare tutti gli ambienti come perfettamente diversi tra loro è stata quantificata anche la dissomiglianza. Questa classificazione si basa su una serie completa di variabili che influenzano fortemente le variazioni geografiche nei modelli biotici. La risoluzione è di 1 km². I 90 strati risultanti (68 nella Spagna peninsulare e Isole Baleari, 22 nelle Isole Canarie) possono essere aggregati gerarchicamente a seconda del livello di generalizzazione richiesto.

Anche se è stato costruito soprattutto come un quadro di riferimento spaziale per lo sviluppo della rete Natura 2000, questa classificazione è stata concepita come uno strumento coerente a livello nazionale per il monitoraggio, il reporting e la gestione di una serie di questioni, compresa la biodiversità e l'uso del territorio.

Parole chiave: clustering, classificazione ecologica del terreno, gradiente ambientale, stratificazione ambientale, classificazione gerarchica.

Introduction

Environmental management is being approached from an increasingly unanimous integrative perspective (CBD, 2008). From this perspective, identifying and classifying ecologically significant geographical units – those capable of reflecting the concurrence and interaction of several environmental components – is an essential task, since it provides the spatial framework needed to support this kind of management (González Bernáldez, 1982; Sims *et al*., 1996; Margules & Pressey, 2000).

There are numerous ecologically-based land classification experiences (or experiences that can be understood as such) in different parts of the world and on different scales (e.g. Holdridge, 1947; Walter & Box, 1976; Ecoregions Working Group, 1989; Klijn *et al*., 1995; Bailey, 1997; Elena-Rosselló, 1997; Montes *et al*., 1998; Fairbanks & Benn, 2000; Olson *et al*., 2001; Leathwick *et al*., 2003; Metzger *et al*., 2005). In Spain, after the publication of Willkomm's academically-oriented work on Iberian steppes (Willkomm, 1852) and the appearance of the applied-oriented "Geographical, geological and agricultural description of Spain" (Coello *et al*., 1859), there have been successive proposals for what is essentially environmentally-based national or peninsular regionalization (Casals, 1998). Examples of this succession include the classical landscape synthesis of Dantín Cereceda (1922) and Hernández-Pacheco (1955-1956), the biogeographcial sectorization of Rivas-Martínez *et al*. (2002), the bioclimatic typology of Allué (1990), the map of vegetation series of Spain (Rivas-Martínez, 1987), the map of potential plant landscapes (Sainz *et al.* 2009), the biogeoclimatic classification of the Elena-Rosselló group (1997) and the ecosystem classification based on functional attributes of Alcaraz *et al*. (2006).

Most of these proposals are based on the authors' personal interpretations and judgments, which poses a problem when it comes to updating, reproducing and using them to design objective sampling. Moreover their utility in biodiversity analysis and management is oftenly compromised by their low resolution.

The land classification described herein uses a statistical approach to define the classes, is based on a reduced set of factors that are directly responsible for land environmental patterns and identifies areas with similar ecological conditions on different scales, regardless of their geographical location in Spain. The basic classification units are 1 km^2 cells.

It also attempts to take advantage of the increasing analytical capabilities of computers, the availability of new databases and the continuous advances in the fields of mathematical modeling and geographic information systems.

It was primarily constructed as a spatial reference framework for the development of the Natura 2000 network in Spain, but because of its explicit nature, flexibility and resolution, it is considered appropriate for the objective stratification of biological samples and a scientific basis for environmental management at the national or peninsular level.

The units identified in this stratification are comparable to ecosystems if one uses a pragmatic interpretation of this concept, along the same lines as the ecological land classification (Rowe & Sheard, 1981; Sims *et al*., 1996). Similarly, the hierarchy revealed by the classification can be interpreted using the hierarchical model for ecosystem organization (Allen & Starr, 1982; Klijn & Udo de Haes, 1994). However, the adoption of a practical point of view should not preclude the recognition of the open and dynamic nature of ecosystems (Evans, 1956) and, consequently, the somewhat arbitrary nature of the geographical limits established.

Materials and methods

The methodological steps involved with this approach were as follows:

- Selection of variables
- Correlation analysis and transformation of the selected variables
- Non-hierarchical classification (of the 1 km^2 cells): identification of environments
- Hierarchical classification (of environments): relations between environments

This methodology was applied separately to Iberian-Balearic Spain and to the Canary Islands.

SELECTION OF VARIABLES

The selection of variables was based on the following main considerations:

- It is possible to identify certain factors that are directly responsible for the environmental patterns into which the land is structured on a given scale. On small or coarse scales, abiotic factors are more important while on large or fine scales biotic factors are also significant (Bailey, 1987; Klijn & Udo de Haes, 1994).
- The choice of variables that are as independent as possible from one another facilitates the interpretation of results and avoids possible collinearity problems (Griffith & Amerhein, 1997).
- Variables that are more stable in time are preferred over those that are less stable. This preference is justified by the durability of the results and because it allows us to identify ecosystems regardless of the degree of disturbance affecting the less stable components, such as vegetation (Bailey, 2005).
- If we understand the reasons why vegetation is distributed we have the key to predicting and understanding a wide range of large-scale ecological responses (Ostendorf *et al*., 2000).

With the foregoing theoretical basis and a national or Iberian-wide application in mind, it was decided that the land classification should be based on abiotic factors, essentially climatic and geological, choosing among them those which are known to be closely related to the principal physiological processes and the distribution of plant communities and species.

CLIMATE

The climatic variables (Tab. 1) were modeled with a resolution of 1 km^2 by the National Institute of Meteorology, according to the method proposed by Ninyerola *et al.* (2000). The data used were recorded between 1971 and 2000 by the meteorological stations scattered throughout Spain.

SOIL AND GEOLOGY

Faced with the impossibility of obtaining suitable data on relevant edaphic variables (water retention capacity, pH, contents of specific nutrients), we looked for indirect geological indicators. This ultimately led to the reclassification of the 1:500,000 scale lithological map of Oriol Riba *et al.* (Riba *et col*., 1969) into five lithological classes as possible values of the lithological variable (L): calcareous rocks (CR), acid siliceous rocks (SAR), basic siliceous rocks (SBR), calcareous and evaporitic sediments (CS) and siliceous

Mean annual temperature (MAT)
Mean temperature of coldest month (MTC) [1]
Mean temperature of hottest month (MTH) [1]
Total annual precipitation (= Mean annual precipitation) (MAP)
Total summer precipitation (June, July August) (TSP)
Total spring precipitation (March, April, May) (TSRP)
Total winter precipitation (December, January, February) (TWP)
Dryness (measured as the quotient between total annual precipitation and potential evapotranspiration) (P/PET)
Mean annual solar radiation (R)
Continentality (Gorczynski Index) (C)
Lithology (L) (Iberian Peninsula and Balearic Islands only)
Slope (s) (Canary Islands only)

[1] The mean temperatures of the coldest month and the hottest month replace the originally selected mean of the lowest temperatures of the coldest month and mean of the highest temperatures of the hottest month, since they had not been modeled for all of the territory.

Tab. 1 - Variables selected for the analysis.

sediments (SS). When the same cell contained various lithologies, we chose that which occupied the greatest surface area. These classes were not considered in the Canary Islands because the siliceous or calcareous nature of the substrate was thought to have only a minor biological implication there.

Topography

Among the different variables used to describe topography, slope (s) is one of the simplest, most descriptive and most significant estimators (Dikau, 1990; Abbate *et al.*, 2006). It was considered to be of some importance in the more uneven territories (Canary Islands), primarily due to its influence on the soil water holding capacity. It was estimated based on altitude in a digital terrain model with a 100 m resolution (National Geographic Institute), taking the average value within each 1 km^2 cell.

Correlation analysis and transformation of the selected variables

To eliminate the negative effects of redundancy due to the high correlation between variables, one of each pair with a Pearson correlation coefficient (*r*) higher than 0.9 was eliminated. When deciding which variable to eliminate, the correlation between the pair of variables and the rest was taken into account. To prevent the variables with a higher variability range from defining greater dissimilarities between the cells being compared (see the next section), the variables were standardized to an average of 0 and a standard deviation of 1.

The lithology was converted into an ordinal variable that reflects the level of consistency of the rock and its pH (acidity). With regard to consistency: CS = SS < CR < SBR = SAR; with respect to pH: CS = CR < SBR < SAR = SS. Each lithological category was assigned a unique numeric value using a metric multidimensional scaling of the two ordinal variables used to define it.

Non-hierarchical classification (of the 1 km^2 cells): identification of environments

The 1 km^2 cells were grouped by dissimilarity, calculated as the Euclidean distances between the values of the variables analyzed (Legendre & Legendre, 1998). The medioid classification technique was used, and executed in R package (R Development Core Team, 2005) applying the *Clara* and *Pam* functions from the *Cluster* library (Maechler *et al.*, 2005). Compared to mean-based classifications, those based on medioids are less sensitive to outsiders (Kaufman & Rousseeuw, 1990).

Non-hierarchical classifications divide the data into a number of groups predetermined by the user. There are different empirical approaches for determining the ideal number of groups. The strategy used in this work was determined primarily by the computational limitations associated with processing a large amount of data. First of all, the input matrix (composed of the descriptor values in each cell) was systematically resampled, selecting one of every 49 cell in regular sequence so as to cover the entire area under study. The resulting reduced matrix then underwent numerous non-hierarchical partitions, testing sets ranging between 20 and 100 groups in each one. The optimal number of groups was determined by comparing the silhouette coefficient values, which measure the degree of overall consistency of each group (Kaufman & Rousseeuw, 1990). Next, there was a second resampling process, this time random, after which the data were grouped non-hierarchically into the optimal number of groups defined in the previous step. To reduce the uncertainty associated with the resampling process and random data selection, the procedure was repeated twenty times.

Using this protocol, the selected cells (1 of every 49) were divided into as many groups as exemplary cases (medioids) were required. The rest of the original cells were assigned to that case from which they were less distant using the *Knn1* function from the *MASS* library

(Venables & Ripley, 2002).

Hierarchical classification (of the environments): relations between environments

The degree of similarity between the groups defined using the procedure described above was estimated by means of a hierarchical classification of the medioids or exemplary cases using the complete linkage (furthest neighbor) technique (Legendre & Legendre, 1998). This technique increases the contrast between different groups by imposing a structure on the input data, something that was appropriate for our purposes. To do so, the *Agnes* function from the *Cluster* library was used (Maechler *et al.*, 2005; Struyf *et al.*, 1997). The results were displayed as a dendrogram.

Results

Correlation analysis of the selected variables

The correlation matrix for the selected variables for Iberian-Balearic Spain and the Canary Islands is shown on Table 2. To offset the negative effect of correlations that are too high (|r| ≥ 0.9), the variables MAT, TAP, TSRP and TWP (Canary Islands) were excluded from successive analyses.

Hierarchical classification: identification of environments

Figure 1 shows the results of the non-hierarchical classification of the 1 km^2 cells, where k = 68 is the optimal number of groups for Iberian-Balearic Spain and k = 22 is the optimal number of groups for the Canary Islands.

	C	**P/PET**	**MAP**	**TWP**	**TSRP**	**TSP**	**R**	**MAT**	**MTC**	**MTH**	**S**
C	1.00	-0.43	-0.47	-0.51	-0.43	-0.10	-0.11	0.83	0.89	0.58	-0.36
P/PET	0.75	1.00	**0.99**	**0.98**	**0.98**	0.80	-0.39	-0.68	-0.65	-0.72	0.53
MAP	0.69	**0.98**	1.00	**0.99**	**0.99**	0.80	-0.31	-0.72	-0.69	-0.76	0.53
TWP	0.60	0.86	**0.93**	1.00	**0.97**	0.74	-0.33	-0.74	-0.71	-0.75	0.55
TSRP	0.67	**0.98**	**0.98**	0.87	1.00	0.83	-0.30	-0.70	-0.66	-0.74	0.52
TSP	0.56	0.76	0.70	0.40	0.76	1.00	-0.21	-0.43	-0.38	-0.57	0.34
R	-0.70	-0.77	-0.67	-0.47	-0.71	-0.76	1.00	-0.14	-0.14	-0.15	-0.27
MAT	-0.32	-0.54	-0.46	-0.24	-0.53	-0.72	0.64	1.00	**0.99**	**0.93**	-0.40
MTC	0.03	-0.28	-0.21	0.00	-0.29	-0.57	0.45	**0.93**	1.00	0.89	-0.39
MTH	-0.70	-0.74	-0.66	-0.45	-0.70	-0.79	0.79	**0.90**	0.69	1.00	-0.35
S	-	-	-	-	-	-	-	-	-	-	1.00

Tab. 2 - Correlation matrix between the quantitative variables analyzed for Iberian-Balearic Spain (bottom left) and Canary Islands (top right). r ≥ 0.9 values in boldface. See Table 1 for meaning of acronyms.

Hierarchical classification: relations between environments

Dendrograms in Figure 2 represent the estimated relations between the environments identified above. The hierarchy of these relations allows us to explore different levels of stratification from an environmental point of view, depending on how the classification is to be used. Figures 3 to 6 show three such levels for Iberian-Balearic Spain and two for the Canary Islands. The map representation of the environments on level 3 (Fig. 5) was created using an automatic procedure of color assignment which, unlike the random palette such as the one used in Figure 1, highlights the similarity between the environments (strata of similar colors have similar environments) and the more or less gradual nature of the environmental changes on the land (Hargrove & Hoffman, 1999). This procedure uses the condensation of environmental variables in a Principal Components Analysis (PCA) using the average values of the variables for each environment. Next, each one of the first three orthogonal principal-component axes of variation resulting from the PCA is assigned an RGB (red, green, blue) color, so that each environment possesses a specific combination of red, green and blue and hence a characteristic color that indicates the relative mix of each environmental component.

The three principal-component axes explain 78% of the data variance. The first axis (50.74% of variance explained), which was assigned the red color, is strongly and positively correlated with radiation and temperature and negatively with dryness (P/PET) and precipitation (total and seasonal). Hence, areas with high contents of red, such as the south-eastern part of the Iberian peninsula and the Guadalquivir valley, indicate environments with a great deal of available energy, little precipitation and a serious water deficit. On the contrary, areas with high cyan content (complementary color of red), such as the Cantabrian coast, reveal environments with minimal available energy, high precipitation and non-existent water deficit.

The second axis (15.95% of variance explained), which was assigned the color green, is negatively correlated with temperature (mean of the coldest month and annual mean) and with the acidity of the substrate and, to a lesser extent and positively, with summer precipitation. Elevated amounts of green, as can be seen in the central Pyrenees, are associated with minimum temperatures and low mean annual temperatures, with a predominance of calcareous (basic) substrates and maximum summer precipitation.

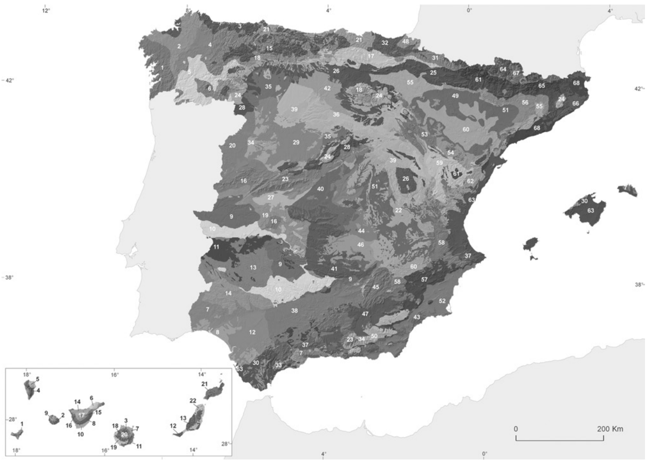

Fig. 1 - Land environments of Spain obtained from a non-hierarchical classification of 1x1 km cells.

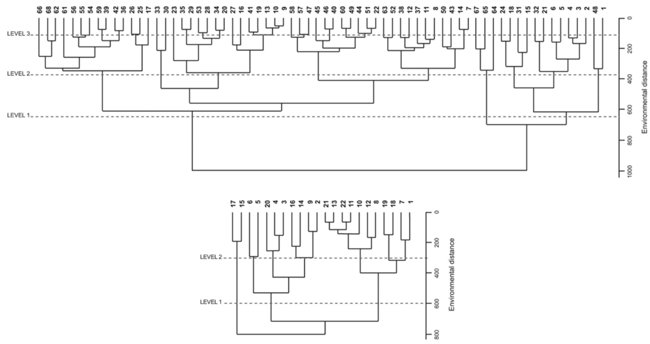

Fig. 2 - Relations between the 68 environments identified for the Iberian-Balearic Spain (top) and the 22 identified for the Canary Islands (bottom). The classification levels represented in figures 3 to 6 are shown in red.

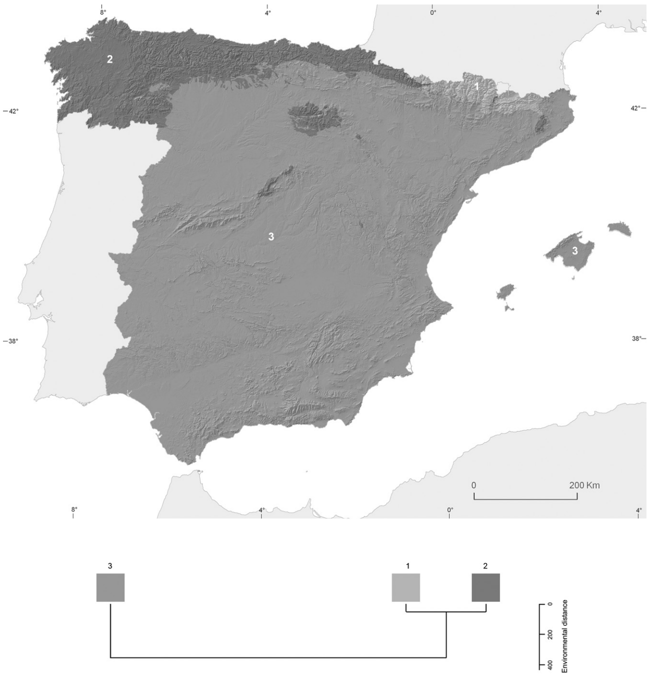

Fig. 3 - Land environments of Iberian-Balearic Spain on Level 1 of the classification.

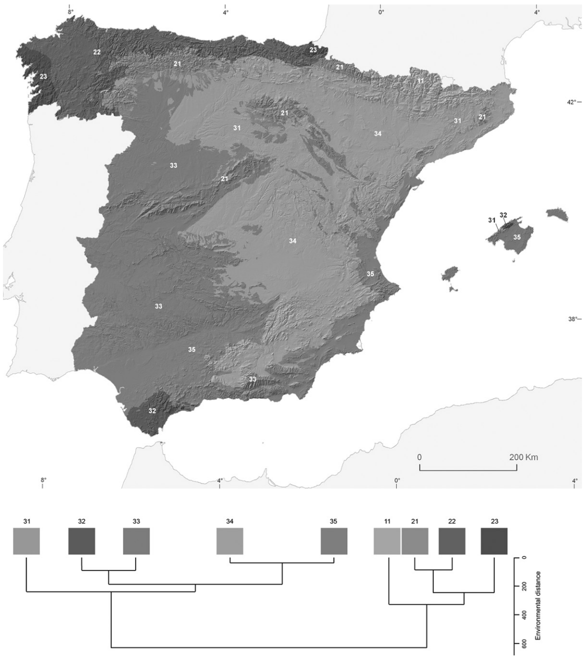

Fig. 4 - Land environments of Iberian-Balearic Spain on Level 2 of the classification.

Elevated amounts of magenta (complementary color of green), as seen in the mountain chains of Cádiz, indicate high minimum and mean annual temperatures, a predominance of acidic siliceous substrates and low summer precipitation.

The third axis (11.16% of variance explained), which was assigned the color blue, is linked to the nature of the substrate, the mean temperature of the coldest month and the opposite of continentality. An elevated amount of blue, such as is seen on the Cantabrian coast, denotes an abundance of calcareous substrates, high minimum temperatures and a lack of continentality. An elevated amount of yellow (complementary color of blue), such as can be seen in a large part of the north-central plains and Sierra Nevada, reveals environments with acidic siliceous substrates, accentuated low temperatures and a marked continentality.

On levels 1 and 2 of the classification for Iberian-Balearic Spain, the color of each environment was obtained from the mean color (red, green, blue) of the level 3 environments grouped into the said environment.

Discussion

The variables used in this classification were chosen considering, first of all, their congruence with the established conceptual framework. According to that framework, it was necessary for climatic factors to play an essential role in the classification, hence their prominence in the overall set of variables. However, depending on this premise posed the risk of such domination masking the role of less prominent variables, in this case lithology and topography. Moreover, the different texture of the types of variables used could also have a negative effect on the results of the overall analysis. In an attempt to recognize artifacts that could possibly be provoked by this situation, different combinations of variables were analyzed: climatic only, climatic and lithological, and finally climatic, lithological and topographical. The results confirmed that the influence on the classification of climatic and lithological variables was apparently consistent with what was expected using the chosen theoretical framework. Hence, it is perfectly consistent with the said framework that at levels 1 and 2 the environments are exclusively or primarily defined by climate, that between levels 2 and 3 all of the limits between the most disparate substrates are revealed (by consistency and pH), SAR y CS, and that lithological differences come into place at level 3 based, for example, on consistency (CR, CS; SAR, SS), but not on pH, and minor climatic differences, e.g. the differences between environments 353 and 354. All of the results are generally plausible and do not appear to reveal significant artifacts, which indicates that the interactions between the different variables and their relative prominence in the definition of units would appear to be appropriate, or that the classification technique used is robust enough to prevent spurious bias towards certain variables.

An alternative to slope as a topographical variable, given the relative ease and the low cost of obtaining this type of variable using a digital terrain model, would have been to use a greater number of variables or combinations of them in appropriate indices. However, it must be remembered that the purpose of the topographical variable in this case is not topographical characterization but rather to serve as a surrogate for the distribution of soil moisture. The suggested alternative does not always increase the predictive value as a surrogate –a value which is limited anyway, given the random component in hydrological processes (Western *et al*., 1999)– but does increase variance (inevitably associated with the estimation of new parameters) and makes the interpretation of results more difficult. Therefore, we preferred to choose the most simple, descriptive and significant indicator possible, such as slope, aside from altitude, implicitly considered in the climatic variables (modeled using altitude and other parameters).

Data availability is a factor that has a secondary yet determining influence on the choice of variables. In our case, the impossibility of obtaining useful data on fog drip (horizontal precipitation) seems to limit locally the effectiveness of the classification, primarily on the western Canary Islands (Tenerife, La Palma, La Gomera and El Hierro), where the so-called “mar de nubes” (cloud sea) has strong ecological implications, but also in some of the eastern mountains of the Cantabrian range.

In the Canary Islands, the absence of a horizontal precipitation variable is likely responsible for the observation of a correlation not as straightforward as could be expected between the identified environments and the traditionally recognized ecological regions. This may also be partially due to the need for greater resolution on the islands with the greatest unevenness. However, the environments identified do seem to reflect, albeit simply, the underlying ecological reality. For example, the first stratification level shown (Fig. 6) consists of three climatically and topographically well characterized environments. Environmental domain 1 comprises the territories that are subject to a marked water deficit and are less steep. It is characterized by the development of the most xerophylous plant communities: prickly scrublands dominated by *Launaea arborescens* (Batt.) Murb., succulent scrublands dominated by *Euphorbia* L. spp. and *Kleinia* Mill. sp., dune formations dominated by *Traganum moquini* Webb *ex* Moq., littoral formations under saline syndrome, the driest variations of the thermophilous forest and what is known as the dry pine forest of *Pinus canariensis* C. Sm. *ex* DC. Environmental domain 2 includes the lands subjected to a moderate water deficit, which is sometimes attenuated or even neutralized by the condensation of atmospheric humidity. It includes those areas directly influenced by the ”cloud sea”, where the water contributed by this source can be even greater than the water received through precipitation. Temperatures are mild year-round and the topography is extremely rough. This domain is characterized by the development of the “monteverde” (”fayal-brezal” or *Erica arborea-Myrica faya* forest, and ”laurisilva” or laurel forest) and the most humid variations of the pine forest and thermophilous forest. Environmental domain 3 comprises cold stressed lands (with more or less lengthy periods of frost and very accentuated daily thermal fluctuations). The radiation is always very intense and the precipitation scarce. It is characterized by high mountain scrublands: broom-like scrubland

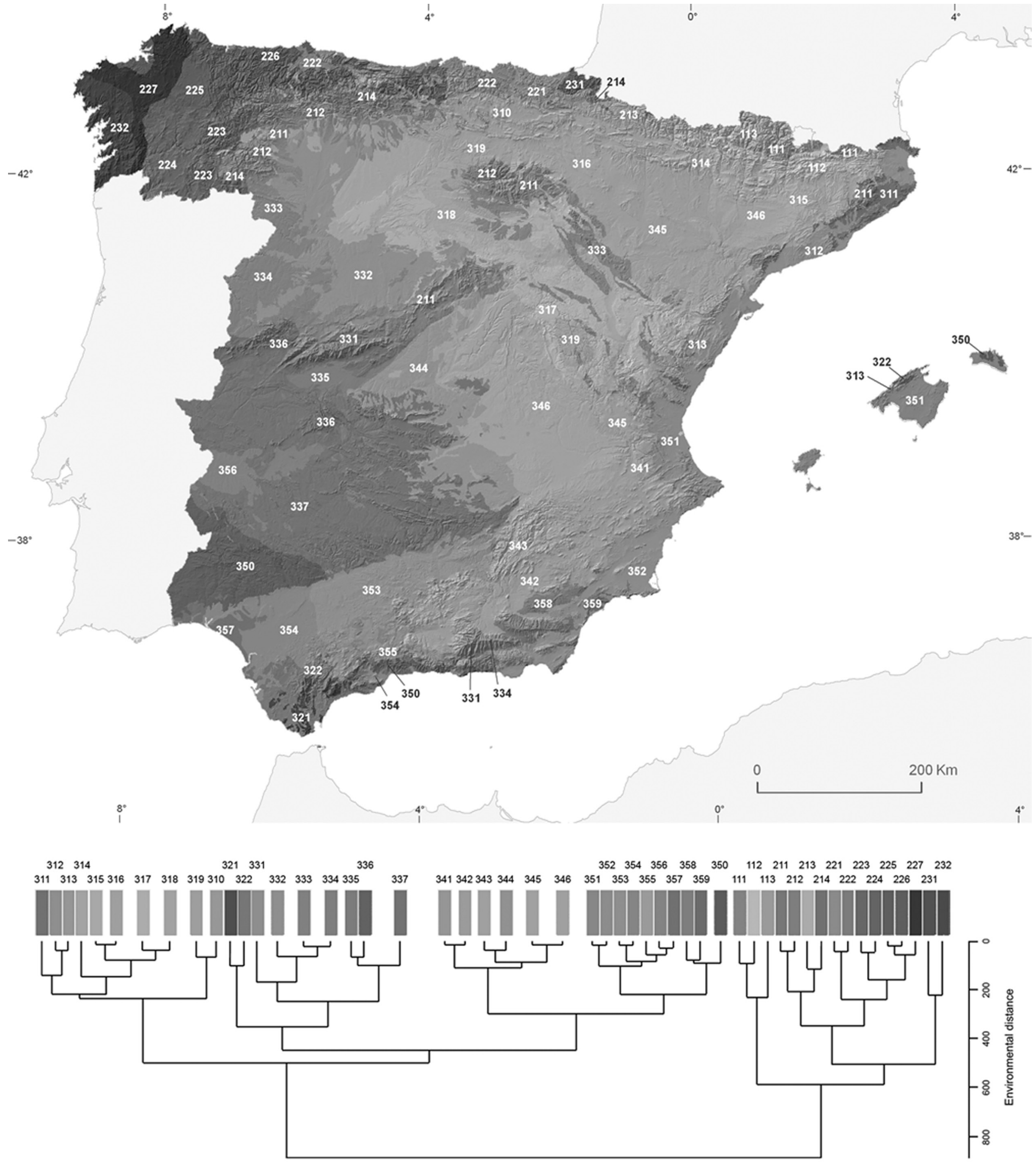

Fig. 5 - Land environments of Iberian-Balearic Spain on Level 3 of the classification. For this map we used an automatic color assignment procedure that makes it possible to display the particular characteristics of each environment, the similarities between them and the more or less gradual nature of environmental change within the territory (see text).

(*Spartocytisus supranubius* (L. f.) Christ *ex* G. Kunkel*, Adenocarpus viscosus* Webb & Berthel.) on the most consolidated substrates; and scrublands dominated by small shrubs and herbaceous plants (*Descurainia bourgeauana* (E. Fourn.) O. E. Schulz*, Erysimum scoparium* (Brouss. *ex* Willd.) Wettst.*, Pterocephalus lasiospermum* Link *ex* Buch*, Viola cheiranthifolia* Humb. & Bonpl.*, Stemmacantha cynaroides* (C. Sm. *in* Buch) Dittrich.*, Silene nocteolens* Webb & Berthel.) on the less consolidated substrates.

The land classification also reveals interesting environmental similarities within Iberian-Balearic Spain, many of them already described in other classifications, particularly biogeographical ones. For example, the map shown as a first stratification level (Fig. 3) contains three environmental domains

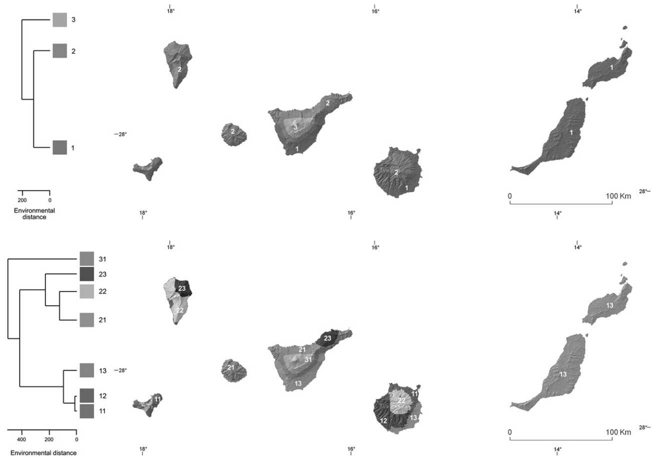

Fig. 6 - Land environments of the Canary Islands on Levels 1 (top) and 2 (bottom) of the classification.

that broadly coincide with the Atlantic, Alpine and Mediterranean biogeographical units (Rivas-Martinez *et al.,* 2002; EEA, 2008). But in addition, at this level and as shown in figure 4, is evidenced the environmental affinity between the mountain ranges limiting the Meseta (Iberian *plateau*) to the north, the western Pyrenees and the chains and enclaves which, although farther away from the influence of the cyclonic fronts and moist winds that reach Iberia from the northwest, are practically unaffected by summer water deficit. This is due to the influence of other fronts (Montseny massif in the northeast) or to the abundance of summer storms (Guadarrama, Ayllón and Valdemeca mountain chains; and Moncayo and Penyagolosa massif in the centre and east respectively), and to regional minimum values of solar radiation and a cool thermoclimate which moderates evapotranspiration. Interestingly, all of these places contain beech forests (*Fagus sylvatica* L.) or recent beech fossil remains .

The environmental land classification of Spain offers the possibility of stratifying the land at different levels of aggregation/deaggregation using classes unambiguously defined and strata with maximum internal homogeneity. Versatility, objectivity and homogeneity are three prominent aspects of this and other quantitative land classifications, primarily because of how they help to understand complex environmental patterns and the effectiveness they bring to their application (Hargrove & Hoffman, 2005; Lugo *et al*., 1999). However, a classification will only be useful if it is capable of adequately representing some type of real ecological pattern, i.e., if the units include, for example, similar ecological processes or functional groups of species. Ultimately, the recognition of its validity will depend on this capability.

In practice, the validity of a stratification system is judged by comparison with previous stratifications and, less frequently, by analyzing the correlation with independent ecological data. Either one of these exercises is useful as means of understanding the scope of the stratification more clearly but is generally ineffective as an authentic validation tool due to a number of problems that are difficult to overcome. Actually, every stratification is inherently different than any other, so that only limited concordance can be expected between them. An estimate of similarities cannot be used as a validation criterion or as the basis for preferring one classification over another due, quite simply, to the fact that they represent alternative hypotheses. The identification of an adequate null hypothesis with which to establish significance is an unresolved issue (Hargrove & Hoffman 2005). In addition, due to the uniqueness of each classification, statistical comparison to detect significant similarities or differences requires transformations (which have a direct effect on resolution and the number of classes) whose implication on results is not usually objectively evaluated. Moreover, using independent ecological data to verify the stratification is difficult considering that such data must refer to ecological process responsible for generating spatial patterns on the same scale as the stratification being evaluated. For example, vegetation would be assumed to offer a good set of data for this purpose, but it is usually complicated to identify an appropriate classification criterion for the vegetation, i.e. that results in a scale comparable pattern, and to obtain the data that would result from applying such criterion. Furthermore, anthropic degradation acts as a limiting factor by modifying the composition of species and biological types, making it necessary to work with a hypothesis on potential vegetation that must likewise be validated.

In short, since each classification represents a hypothesis about the factors that control the structure and function of ecosystems, it is necessary to find a means of validating or verifying the hypothesis. However, it is also a particular simplification of reality and therefore does not seem right to pursue an exact correspondence with any existing model (based on their own criteria and their own Achilles' heel) or with reality itself. Rather, a consistent model from a theoretical perspective must be developed which is transparent and sufficiently useful (effective and robust) and whose strengths and weaknesses can be clearly identified. In this regard, an approach such as that of the Land Environments of Spain, based on an explicit conceptual model and that uses a consistent and sufficiently proven methodology, could be expected to meet these requirements and to ultimately contribute to a better understanding of the land in question and to successfully resolve environmental management and analysis problems.

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References

Abbate G., Cavalli R. M., Pascucci S., Pignatti S. & Poscolieri M., 2006. Relations between morphological settings and vegetation covers in a medium relief landscape of Central Italy. Annals of Geophysics 49:153-165.

Alcaraz D., Paruelo J. M. & Cabello J., 2006. Identification of current ecosystem functional types in the Iberian Peninsula. Global Ecology and Biogeography 15: 200-212.

Allen, T. F. H. & Starr, T. B., 1982. Hierarchy: perspectives for ecological complexity. The University of Chicago Press. Chicago.

Allué J. L., 1990. Atlas fitoclimático de España. Monografías I.N.I.A. 69. Ministerio de Agricultura, Madrid.

Bailey R. G., 1987. Suggested hierarchy of criteria for multiscale ecosystem mapping. Landscape and Urban Planning 14: 313-319.

Bailey R. G., 1997. Map. Ecoregions of North America (rev.). USDA Forest Service, Washington DC, scale 1: 15.000.000.

Bailey R. G., 2005. Identifying ecoregion boundaries. Environmental Management 34: 14-26.

Casals V., 1998. Gestión ambiental y regionalización: una aproximación histórica al caso español. Scripta Nova, Revista Electrónica de Geografía y Ciencias Sociales 16.

CBD 2008. Ecosystem approach. UNEP/CBD/COP/Decision IX/7. Bonn, Germany, 19-30 May 2008.

Coello F., Luxan F. & Pascual A., 1859. Reseñas geográfica, geológica y agrícola de España. Imprenta Nacional, Madrid.

Dantín Cereceda J., 1922. Ensayo acerca de las regiones naturales de España. Tomo I. Museo Pedagógico Nacional, Madrid.

Dikau R., 1990. Geomorphic landform modelling based on hierarchy theory: Proceedings 4th International Symposium on Spatial Data Handling, Zürich, Switzerland, July 23-27, 1: 230-239.

Ecoregions Working Group 1989. Ecoclimatic Regions of Canada, First Approximation. Ecological Land Classification Series, No. 23, Environment Canada, Ottawa.

EEA, 2008. Biogeographical regions, Europe 2008. European Environment Agency, Copenhagen.

Elena-Rosselló R. (Ed.), 1997. Clasificación biogeoclimática de España peninsular y balear. Ministerio de Agricultura, Pesca y Alimentación. Madrid.

Evans F. C., 1956. Ecosystems as the basic unit in Ecology. Science 123: 1127-1128.

Fairbanks D. H. K. & Benn G. A., 2000. Identifying regional landscapes for conservation planning: a case study from KwaZulu-Natal, South Africa. Landscape and Urban Planning 50: 237-257.

González Bernáldez F., 1982. Análisis ecosistémico de los recursos naturales. Publicaciones del Centro Internacional de Formación en Ciencias Ambientales (CIFCA), Serie Medio Ambiente, 2.

Griffith D. A. & Amerhein C. G., 1997. Multivariate statistical analysis for geographers. Prentice Hall, Englewood Cliffs, New Jersey.

Hargrove W. W. & Hoffman F. M., 1999. Using multivariate clustering to characterize ecoregion borders. Computing in Science and Engineering 1(4): 18-25.

Hargrove W. W. & Hoffman F. M., 2005. Potential of multivariate quantitative methods for delineation and visualization of ecoregions. Environmental Management 34, Suppl. 1: 39-60.

Hernández-Pacheco E., 1955-1956. Fisiografía del solar hispano. Memorias de la Real Academia de Ciencias Exactas, Físicas y Naturales de Madrid, Serie Ciencias Naturales 16 (1-2).

Holdridge L. R., 1947. Determination of world plant formations from simple climatic data. Science 105: 367-368.

Kaufman L. & Rousseeuw P. J. (eds.), 1990. Finding groups in data. An introduction to cluster analysis. Wiley-Interscience.

Klijn F. & Udo de Haes H. A., 1994. A hierarchical approach to ecosystems and its implications for ecological land classification. Landscape Ecology 9: 89-104.

Klijn F., Dewaal R. W. & Voshaar J. H. O., 1995. Ecoregions and ecodistricts. Ecological regionalizations for The Netherlands environmental policy. Environmental Management 19: 797-813.

Leathwick J. R., McOverton J. & McLeod M., 2003. An environmental domain classification of New Zealand and its use as a tool for biodiversity management. Conservation Biology 17: 1612-1623.

Legendre P. & Legendre L., 1998. Numerical Ecology. Elsevier, New York.

Lugo A. E., Brown S. L., Dodson R., Smith T. S. & Shugart H. H., 1999. The Holdridge life zones of the conterminous United States in relation to ecosystem mapping. Journal of Biogeography 26: 1025-1038.

Maechler M., Rousseeuw P., Struyf A. & Hubert M., 2005. Cluster Analysis Basics and Extensions. Unpublished. R package version 1.10.2.

Margules C. R. & Pressey R. L., 2000. Systematic conservation planning. Nature 405: 243-253.

Metzger M. J., Bunce R. G. H., Jongman R. H. G., Mücher C. A. & Watkins J. W., 2005. A climatic stratification of the environment of Europe. Global Ecology and Biogeography 14: 549-563.

Montes C., Borja F., Bravo M. A. & Moreira J. M. (cord.), 1998. Reconocimiento biofísico de espacios naturales protegidos. Doñana: una aproximación ecosistémica. Junta de Andalucía, Consejería de Medio Ambiente.

Ninyerola M., Pons X. & Roure J.M., 2000. A methodological approach of climatological modelling of air temperature and precipitation through GIS techniques. International Journal of Climatology 20: 1823-1841.

Olson D. M. et al., 2001. Terrestrial ecoregions of the world: a new map of life on earth. BioScience 51: 933-938.

Ostendorf B., Hilbert D. W., Köstner B., Tappeiner U. & Tasser E., 2000. Toward a predictive understanding of ecosystem processes at the scale of landscapes. In Oxley L., Scrimgeour F. & McAleer M. (Eds.), International Congress on Modelling and Simulation Proceedings, 3: 685-690. The Modelling and Simulation Society of Australian and New Zealand, Camberra.

R Development Core Team 2005. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Viena.

Riba O. et col., 1969. Mapa litológico de España 1:500.000. IGME, Madrid.

Rivas-Martínez S., 1987. Mapa de series de vegetación de España y Memoria. Ministerio de Agricultura, Pesca y Alimentación-ICONA, Madrid.

Rivas-Martínez S., Penas A. & Díaz T. E., 2002. Biogeographic map of Portugal and Spain to sector level. In Rivas-Martínez S., Díaz T. E., Fernández-González F., Izco J., Loidi J., Lousa M. & Penas A. (Eds.), Vascular plant communities of Spain and Portugal. Addenda to the syntaxonomical checklist of 2001. Itinera Geobotanica 15 (1): 5-432.

Rowe, J. S. & Sheard, J. S., 1981. Ecological Land Classification: A survey approach. Environmental Management 5: 451-464.

Sainz H., Sánchez R. & García-Cervigón A.I., 2009. Mapa de paisajes vegetales potenciales. In Hernández L. & Romero F. (Ed.), Bosques españoles. Los bosques que nos quedan y propuestas de WWF para su restauración. WWF/Adena, Madrid.

Sims R. A., Corns I. G. W. & Klinka K., 1996. Introduction-Global to local: Ecological Land Classification. Environmental Monitoring and Assessment 39: 1-10.

Struyf A., Hubert M. & Rousseeuw, P. J., 1997. Integrating robust clustering techniques in S-PLUS. Computational Statistics & Data Analysis 26: 17-37.

Venables W. N. & Ripley B. D., 2002. Modern Applied Statistics with S. Springer, New York.

Walter H. & Box E., 1976. Global classification of natural terrestrial ecosystems. Vegetatio 32: 75-81.

Western A. W., Grayson R. B., Blöschl G., Willgoose G. R. & McMahon T. A., 1999. Observed spatial organization of soil moisture and its relation to terrain indices. Water Resources Research 35: 797-810.

Willkomm M., 1952. Strand- und Steppengebiete der Iberischen Halbinsel und deren Vegetation. Ein Beitrag zur physikalischen Geographie, Geognosie und Botanisil. Leipzig, Fleischer.

Note: a full color version of the maps displayed in the present paper will soon be available as image files as well as shape files for viewing and downloading from http://www.marm.es/es/biodiversidad/.

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