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A new methodology for the quantitative evaluation of the conservation status of vegetation: the potentiality distance index (PDI)

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Abstract

Mapping of the present state of vegetation for the use in nature conservation is a practical and useful application of phytocoenology. Methods of modern phytosociology allow a good scientific evaluation of the biological value of a territory. In this sense, the main aim of this study is to propose an objective and quantifiable scientific index (Potentiality Distance Index, PDI) in order to evaluate the distance to the optimum status (series head) of each territory and therefore its global conservation status.

The Index is based on the application and interpretation of the Symphytosociological or Dynamic-Catenal Phytosociological conception. Thus, taking into account the successional relations of the different types of vegetation and their naturalness indexes is possible to define a formula for evaluating the distance to the series head and therefore to their optimum conservation status. The Index has been tested in different territories of the Iberian Peninsula using the Actual Vegetation Cartography developed for the National Inventory of Natural and Seminatural Habitat Types (Rivas-Martínez *et al*, 1993) in order to determine the protected sites that have constituted Natura 2000.

Results proposed in the current study show the Index is objective and universal because the global conservation status of the studied area is in accord with results proposed by other authors for this territory with similar indexes. The Index can provide objective and quantitative information to be applied in land management and nature conservation studies, being a useful tool for the restoration of potential natural vegetation in degraded areas.

Keywords: Dynamic-Catenal Phytosociology, land management, nature conservation, naturalness index, potential natural vegetation.

Resumen

La cartografía del estado actual de la vegetación para su uso en la conservación de la naturaleza es una aplicación muy útil y práctica de la fitocenología. Los métodos de la fitosociología moderna permiten una buena evaluación científica del valor biológico de un territorio. En este sentido, el objetivo principal de este estudio es proponer un índice científico objetivo y cuantificable (Índice de Distancia a la Potencialidad, PDI) con el fin de evaluar la distancia al estadio óptimo (etapa madura) de cada territorio y, por tanto, su estado global de conservación.

El Índice está basado en la aplicación e interpretación de la metodología sinfitosociológica o fitosociología dinámico-catenal. De este modo, y considerando las relaciones sucesionales de los distintos tipos de vegetación y sus índices de naturalidad, es posible definir una fórmula para evaluar la distancia a la etapa madura y por tanto, a su óptimo estado de conservación. El Índice ha sido aplicado en diferentes territorios de la Península Ibérica tomando como base la Cartografía de Vegetación Actual desarrollada a través del Inventario Nacional de los tipos de Hábitats Naturales y Seminaturales (Rivas-Martínez *et al.*, 1993) con la finalidad de determinar los lugares protegidos que han constituido la Red Natura 2000.

Los resultados propuestos en el presente trabajo indican que el Índice propuesto es objetivo y tiene una aplicación universal ya que el estado global de conservación del área estudiada está en consonancia con los resultados propuestos por otros autores para este mismo territorio aplicando índices similares. El Índice puede ofrecer una información objetiva y cuantitativa que puede ser aplicada en estudios de ordenación del territorio y conservación de la naturaleza, siendo así una herramienta de gran utilidad para la restauración de la vegetación natural potencial de áreas degradadas.

Palabras clave: Fitosociología Dinámico-Catenal, ordenación del territorio, conservación de la naturaleza, índice de naturalidad, vegetación natural potencial.

Introduction

Biological and landscape evaluation of a territory is a fundamental phase in land planning studies, and is carried out at an early stage in order to determine the environmental implications of any development, as well as to assess the territory's suitability for its intended use (Ortega & Rodríguez, 1996).

Plants and plant communities play a fundamental role in this type of evaluation for land management studies, due to their importance as natural and cultural resources. A number of authors (Arnáiz, 1981; Blandin, 1986; Asensi, 1990; Géhu, 1992; Loidi, 1994) have indicated that plant communities result from the interplay of many environmental variables, and represent practically the completely floristic diversity, as well as many of the ecological relationships between the organisms involved. For this reason, knowledge of the flora and vegetation of a territory is fundamental for studying and evaluating its conservation status.

Studies applied to the evaluation of landscape have improved over the last thirty years (Arnáiz, 1981; Géhu 1979, 1981, 1988, 1991, 1992; Géhu & Géhu-Frank 1979, 1981, 1991; Nef, 1980; Tombal & Meriaux, 1981; Blandin, 1986; Costa *et al.*, 1988; Ferreras Chasco, 1988; Martín & Asensi, 1988; Raimondo & Venturella, 1989; Rameau & Bricault, 1988; Richard *et al.*, 1988; Asensi, 1990; Asensi *et al.,* 1991, 1997; Meaza, 1993; Sesma & Loidi, 1993; Cano *et al.,* 1994; Loidi, 1994; Díaz González *et al.*, 1996a, 1996b; Díaz González & Prieto, 1997; Cadiñanos & Meaza, 1998; García-Baquero & Valle, 1998; Giménez & Gómez, 1999; Díaz González & García, 2001).

Criteria used to evaluate plant communities vary widely (Cadiñanos & Meaza, 1998) and include: phytocoenotic criteria (diversity, replaceability, representability, naturalness, maturity); territorial criteria (rarity, endemicity, relictism); mesologic criteria (geomorphology, climatologic, edaphic, faunistic and hydrologic function); cultural criteria (ethnobotanical value) and threat criteria. These criteria can be applied independently for each plant community or by means of compound indices that draw together, several of the elements mentioned above.

One aspect worthy of consideration in this type of studies is that the biological evaluation of a territory will be more objective and easier to perform if formulas can be established to quantify the various environmental elements involved. This quantification, moreover, is essential when dealing with the planning authorities, which tend to be more susceptible to the numerical approach (Costa *et al.*, 1988). In this sense, it may be noted that Phytosociology, and specially Dynamic-Catenal Phytosociology or Symphytosociology, are very useful tools for assessing the environmental quality of a territory and thus for implementing conservation and management plans, since both these sciences are predictive and objective (Gehú, 1981; Bou, 1988; Costa *et al.*, 1988; Asensi, 1990, Asensi *et al.*, 1991).

Phytosociology is a science dealing with biocenosis from a botanical perspective. In other words, it is concerned with plant communities. It studies the floristic composition of plant communities, their distribution and dynamism, as well as the environmental factors that characterize them. All these aspects provide basic information for evaluating and interpreting each plant community.

Nowadays, this phytosociological knowledge has been widened by the addition of the Dynamic-Catenal Phytosociology (=Symphytosociology) to classic or Braun-Blanquet’s Phytosociology (Béguin & Hegg, 1975; Béguin *et al.*, 1979; Rivas-Martínez, 1976, 1985, 1987, 1994, 1996; Géhu & Rivas-Martínez, 1981; Ansseau & Grandtner, 1990; Rivas-Martínez *et al.*, 1999, 2002; Gehú, 1979, 1988, 1991; Asensi, 1996; Alcaraz, 1996; Loidi, 2002). The typological unit in Symphytosociology is the Sigmetum or Vegetation Series. This is a geobotanical notion that attempts to express all plant communities, or collections of serial stages, to be found in similar land units (ecologically homogeneous territory where only one vegetation series can settle within it) as a result from succession processes. Therefore, a vegetation series includes the representative vegetation type of the series head and the initial pre-serial and sub-serial communities replacing it (Rivas-Martínez *et al*., 1999, 2002).

Symphytosociology also considers stable plant communities (permanent plant communities) called microsigmeta (Rivas-Martínez *et al.*, 1999, 2002). These microsigmeta are permanent plant communities delimited by exceptional microtopographic and edaphic features in which a dynamic balance seems to have been reached. Under these conditions, such communities must be considered as mature communities. The most propitious biotopes for microsigmeta development are cliffs and rock crevices, bogs, snowdrifts, mobile dunes, shores of lakes and ponds, etc.

Materials and Methods

Overview

As previously discussed, The Potentiality Distance Index (PDI) is based on Symphytosociological concepts. The formula for calculating PDI considers that the global conservation status of a territory is optimal when the whole of it is at the series head. Thus, having knowledge of the vegetation series and the distance of its serial stages to mature phase in a given area it is possible to evaluate its conservation status independently of other territories.

Formulation

Taking into account concepts above commented, the formula for The Potentiality Distance Index proposed in the current study is as follows:

$$PDI = \sum_{i=1}^{n} DI_i \times \frac{\Omega_i}{\Omega\ TOTAL}$$

where:
PDI= Potentiality Distance Index
i = i-th plant community
Ω_i = surface area of i-th plant community
Ω TOTAL = total surface area occupied by all plant communities
DI_i= potentiality distance value of i-th plant community.

Its formula is as follows:

$$DI_i = 1 - \left(\frac{3P_i - NI_i}{3n} \right)$$

where
P_i = position of i-th plant community in its respective vegetation series in relation to the series head.
NI_i = naturalness index of i-th community
n = number of serial stages in the vegetation series resulting from the succession process.
In microsigmetum n=1 because such plant communities are considered as series head.

Comments regarding n and P_i factors

The P_i value is different depending on the position of each plant community in the succession process. Thus, P_i =1 for mature stages and for microsigmetum; P_i = 2 for the first serial stage, and so on successively down to the most degraded stages in each vegetation series; because they are the ones furthest from the series head. It should be noted that the number of serial stages in a vegetation series differs depending on the vegetation type, bioclimatic and biogeographic characteristics and the edaphic typology of each tesela. For instance, in temperate territories of the Iberian Peninsula where the potential natural vegetation is a forest the number of serial stages is generally 7. If the territory belongs to an oromediterranean thermotype n = 2 and in a tropical pluvial forest the number stages can be up to 9.

Areas occupied by anthropic vegetation and crops, as well as population centres and artificial areas do not form part of any natural succession process. Nevertheless, these surfaces have to be considered in the evaluation, because they are occupying an area within the territory. In such cases, the P_i value to be assigned to these areas is the one next to that assigned to the most distant position from the series head identified in the study area.

Comments regarding the Naturalness Index (NI)

The naturalness criteria considered in this study are those proposed by Asensi, Llorens & Penas (in Díaz *et al.* 1996b), for use in the Cartography and Inventory of Habitat Types, Directive 92/43/EEC. Here, the Naturalness Index (NI) of a plant community is considered as the distance between its final equilibrium stage (series head), and its degree of anthropic influence or successional variation. Thus, NI indicates the degree of conservation of the plant community. Other authors have defined the Naturalness Index in the same way (Arnáiz, 1981; Miyawaki & Fujiwara, 1976; Gehú & Gehú-Frank, 1981, 1991). Therefore, it is specific to each plant community and not constant for the whole territory. The scale used in this index is as follows:

NI=1. For plant communities with low natural conservation and with strong human influence (distance to the optimum stage: >50%)
EXAMPLE: areas occupied by anthropic vegetation and crops as well as construction sites and population centres.
NI=2. For plant communities with relatively high natural conservation and with a low, but appreciable, human influence (distance to the optimum stage: 30-50%)
EXAMPLE: areas occupied by holm-oak woods with modified floristic composition because of sporadic tree felling.
NI=3. For plant communities with high natural conservation without (or with very little) human influence (distance to the optimum stage: <30%)
EXAMPLE: a beech forest with a non-modified floristic and structural composition.

As the degree of human influence on a plant community increases, there is a decrease in plants with a more reduced ecological range and an increase in nitrophilous plants.

Some examples of DI_i values

Some examples of DI_i values for vegetation series with 2, 4, 7 and 9 serial stages (n=2, 4, 7 and 9 respectively) are indicated in Tab. 1.

For instance, the potentiality distance value for a mature community (P_i = 1) with a low human influence (NI=2) belonging to a vegetation series with two serial stages (n=2) is as follows:

$$DI_i = 1 - \left(\frac{(3x1)-2}{3x2} \right) = 1 - \frac{1}{6} = 0.83333$$

Final consideration

Once the PDI formula has been applied, Index values are divided into four groups showing the distance to the series head of the studied area and therefore the global conservation status of vegetation.

To apply this index, it is necessary to draw up the actual vegetation cartography of the territory under study according to Phytosociological principles. In this sense, the cartography developed for the National Inventory of Natural and Seminatural Habitat types in the contex of Natura 2000 has been a fundamental base for the application of the Index.

One or more different types of vegetation up to

PDI	DISTANCE TO SERIES HEAD	CONSERVATION STATUS
0-0.25	VERY DISTANT	POOR
0.26-0.50	DISTANT	MODERATE
0.50-0.75	MODERATELY DISTANT	GOOD
0.76-1	NOT MUCH DISTANT/NO DISTANT	VERY GOOD

'association' or 'plant community' level are represented by means of closed areas or polygons in the actual vegetation map. A numeric or nominal key for distinguishing different plant communities are assigned to each polygon of the map to be studied. The Geographic Information Systems (GISs) used during recent years have been very useful tools for the final design of this type of map because they enable accurate calculations concerning polygon surfaces and other parameters for later evaluation, without requiring comparison with other territories.

Tab. 1 - Some examples of *DI* values in vegetation series with different number of serial stages

SERIAL STAGES (n=2)			SERIAL STAGES (n=4)			SERIAL STAGES (n=7)			SERIAL STAGES (n=9)		
P_i	NI_i	DI_i	P_i	NI_i	DI_i	P_i	NI_i	DI_i	P_i	NI_i	DI_i
1	3	1	1	3	1	1	3	1	1	3	1
1	2	0.8333333	1	2	0.916666667	1	2	0.95238095	1	2	0.96296296
1	1	0.6666667	1	1	0.833333333	1	1	0.9047619	1	1	0.92592593
2	3	0.5	2	3	0.75	2	3	0.85714286	2	3	0.88888889
2	2	0.3333333	2	2	0.666666667	2	2	0.80952381	2	2	0.85185185
2	1	0.1666667	2	1	0.583333333	2	1	0.76190476	2	1	0.81481481
			3	3	0.5	3	3	0.71428571	3	3	0.77777778
			3	2	0.416666667	3	2	0.66666667	3	2	0.74074074
			3	1	0.333333333	3	1	0.61904762	3	1	0.7037037
			4	3	0.25	4	3	0.57142857	4	3	0.66666667
			4	2	0.166666667	4	2	0.52380952	4	2	0.62962963
			4	1	0.083333333	4	1	0.47619048	4	1	0.59259259
						5	3	0.42857143	5	3	0.55555556
						5	2	0.38095238	5	2	0.51851852
						5	1	0.33333333	5	1	0.48148148
						6	3	0.28571429	6	3	0.44444444
						6	2	0.23809524	6	2	0.40740741
						6	1	0.19047619	6	1	0.37037037
						7	3	0.14285714	7	3	0.33333333
						7	2	0.0952381	7	2	0.2962963
						7	1	0.04761905	7	1	0.25925926
									8	3	0.22222222
									8	2	0.18518519
									8	1	0.14814815
									9	3	0.11111111
									9	2	0.07407407
									9	1	0.03703704

An example of PDI application

In order to apply the proposed index, a specific area has been selected to asses its distance to the series head and therefore its global conservation status. The studied area is located in the Valle de Valdeburón (Leon province, Spain) and it has a surface area of 4 km^2 (Fig. 1). Biogeographically, the study area belongs to the Ubinnean Subsector (Ubinnean-Picoeuropean Sector, Orocantabric Subprovince). Bioclimatologically, the territory is Temperate oceanic. Thermotypes in this area are supratemperate and orotemperate and the main

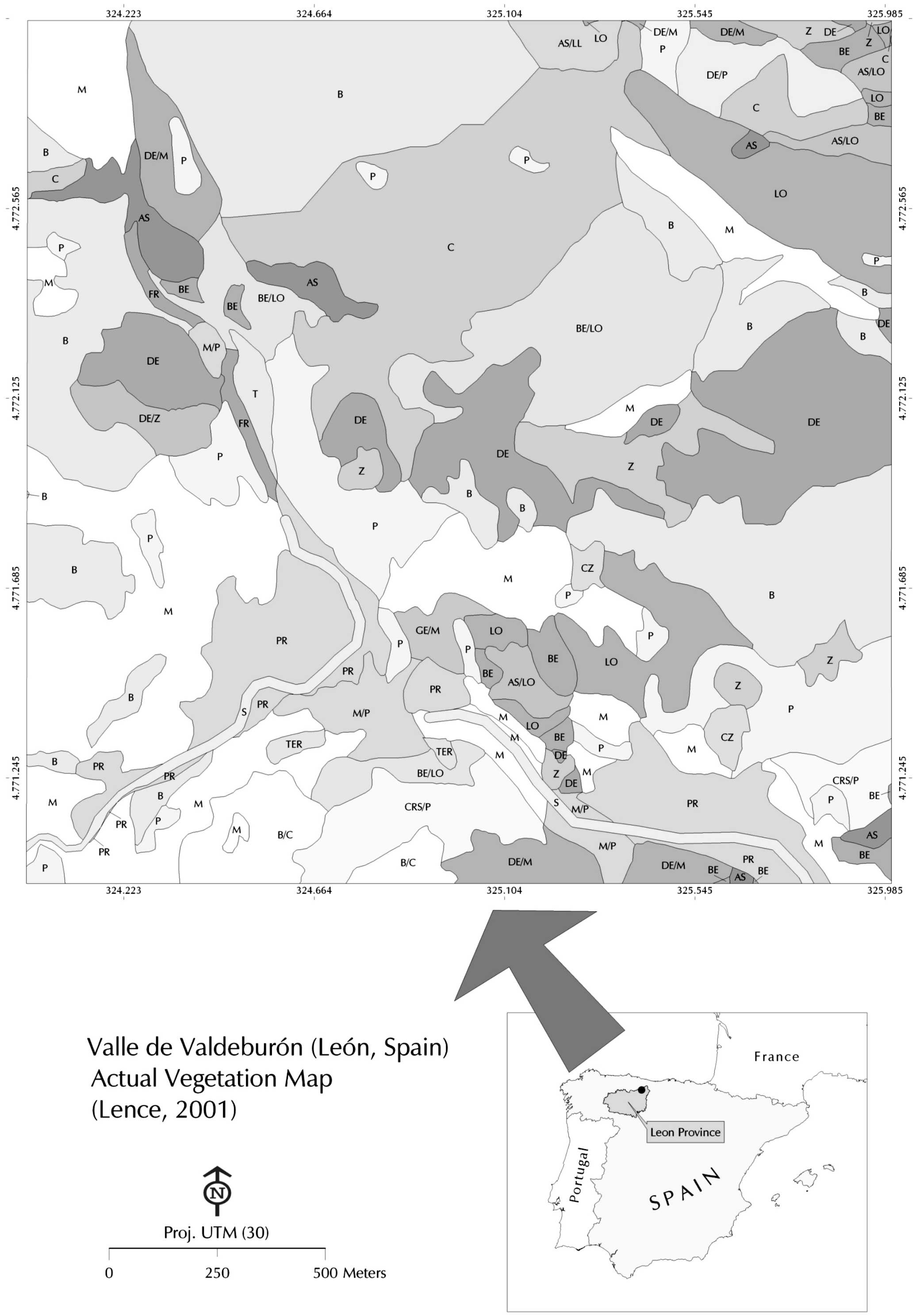

Fig. 1- Actual Vegetation Map of the studied territory

ombrotype is hyperhumid (Lence, unpublished data).

Plant communities of the studied area were analysed taking into account the phytosociological methodology and the Actual Vegetation Map of Valle de Valdeburón (Leon, Spain; E.1:50000) (Lence, unpublished data).

Results and discussion

A total of 135 polygons are represented in the Actual Vegetation Map of the studied territory (Fig. 1) grouping in 19 different plant communities **(**Tab. 2**)**.

The first thirteen plant communities represent different stages of the succession process and they can be grouped into four different vegetation series as follows (C. Lence, unpublished data):

- *Carici sylvaticae-Fago sylvaticae* sigmetum with seven plant communities resulting from the succession process.
- *Blechno spicant-Fago sylvaticae* sigmetum with seven plant communities resulting from the succession process.
- *Salico cantabricae* sigmetum with two plant communities resulting from the succession process.
- *Euphorbio hybernae-Fraxino excelsioris* sigmetum with five plant communities resulting from the succession process.

The remaining plant communities belong to different microsigmeta recognized in the territory.

Tab. 2 shows plant communities represented in the Actual Vegetation Map of the territory with their respective P, NI, n and DI values, together with a nominal key in order to distinguish them. The first column in the table represents the total surface area occupied by each plant community in the territory. This surface-area value is the sum of areas occupied by each

Tab. 2 - Plant communities and PDI in the Actual Vegetation Map of Valle de Valdeburón

Ωi (Km^2)	KEY	PLANT COMMUNITIES	NI	P	n	DI	DI x (Ωi/ΩTOTAL)
0.7410	B	*Blechno spicant-Fagetum sylvaticae* (PNV)	1	1	7	0.90476	0.16760
0.3644	C	*Carici sylvaticae-Fagetum sylvaticae* (PNV)	1	1	7	0.90476	0.08243
0.5393	P	*Cytiso cantabrici-Genistetum obtusirameae* (NFS)	1	3	7	0.61905	0.08346
0.0193	FR	*Euphorbio hybernae-Fraxinetum excelsioris* (PNV)	3	1	5	1	0.00483
0.0120	GE	*Genisto anglicae-Ericetum vagantis* (CHS)	2	5	7	0.38095	0.00114
0.1746	BE	*Helianthemo cantabrici-Brometum erecti* (PGS)	2	4	7	0.52381	0.02287
0.0120	LL	*Lithodoro diffusae-Genistetum legionensis* (CHS)	2	5	7	0.38095	0.00114
0.2986	LO	*Lithodoro diffusae-Genistetum occidentalis* (MCF)	1	5	7	0.33333	0.02488
0.2292	PR	*Malvo moschatae Arrhenatheretum elatioris* (PGS)	1	4	5	0.26667	0.01528
0.6987	M	*Merendero pyrenaicae-Cynosuretum cristati* (PGS)	1	4	7	0.47619	0.08318
0.0091	TER	*Minuartio hybridae-Saxifragetum tridactylitae* (TGS)	1	6	7	0.19048	0.00043
0.5532	DE	*Pterosparto cantabrici-Ericetum aragonensis* (CHS)	1	5	7	0.33333	0.04610
0.0551	S	*Salicetum cantabricae* (PNV)	1	1	2	0.66667	0.00918
0.0555	CRS	*Agrostio duriaei-Sedetum pyrenaici* (MGS)	2	1	1	0.66667	0.00925
0.0003	T	*Anagallido-Juncetum bulbosi* (MGS)	1	1	1	0.33333	0.00003
0.0916	AS	*Anemono pavonianae-Saxifragetum canaliculatae* (MGS)	2	1	1	0.66667	0.01526
0.1148	Z	Community of *Alchemilla saxatilis* and *Juncus trifidus* (MGS)	1	1	1	0.33333	0.00956
0.0177	CZ	*Cryptogrammo crispae-Dryopteridetum abbreviatae* (MGS)	1	1	1	0.33333	0.00147
0.0136	ET	*Eriophoro latifoli-Caricetum lepidocarpae* (MGS)	1	1	1	0.33333	0.00113
Ω TOTAL = 4.00							PDI=0.57925

plant community in the different polygons.

Abbreviations following the name of each plant community are used to indicate the type of vegetation in the succession process.

PNV: potential natural vegetation
PRF: pre-forest or secondary forest
NFS: nanophanerophytic scrub
PGS: perennial grassland
CHS: chamaephytic scrub
TGS: therophytic grassland
MSG: microsigmetum

Once the formula has been applied the PDI value for the studied territory is 0.57925, which tells us the territory is moderately distant to its series head and therefore the global conservation status of vegetation of this area is good.

This fact answers to its inclusion in the Regional Park of Picos de Europa (L 12/1994, July 18) and therefore it does necessary its protection.

Our data are in accord to those proposed for other territories included in the Regional Park Park (Alonso Redondo, 2003; Lence, unpublished data) showing higher values than different Cantabric regions (Babia, Alto Carrión, Omaña, Sª Brezo) not included in this Park (Penas *et al.*, 1993).

Conclusion

The Potentiality Distance Index (PDI) proposed in the current study has a universal application, allowing a good and objective evaluation of the global conservation status of vegetation in a given area and a useful comparison between different territories based on their dynamic characteristics and their naturalness index. Thus, the knowledge of composition and dynamic of plant communities gives perspectives and possibilities of restoration and rehabilitation of potential natural vegetation of degraded areas. In this sense, authorities can thus be provided with a readily applicable tool for establishing priorities in land management and nature conservation policy.

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