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ORIGINAL ARTICLE

Can Ellenberg's indicator values for Mediterranean plants be used outside their region of definition?

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ABSTRACT

Aim The aims of this study are: (1) to explore the relationships between the Ellenberg indicator values (light, temperature and moisture) recently developed for two Mediterranean regions (Italy and Greece); and (2) to evaluate the possibility of using these values in other Mediterranean areas.

Location Southern Greece and the Mediterranean part of Italy.

Methods A global matrix containing 966 items of information (161 species × 3 indicator variables × 2 values assigned in each study, one in Italy and one in Greece) was constructed. A test of the accuracy of the values in predicting actual environmental conditions was provided using a detrended correspondence analysis (DCA) on published vegetation relevés from the Mediterranean region. The gamma statistic was used to express relationships of ecological indicator values between the two regions, and pairs of indicator values calculated for each species were compared using Wilcoxon matched pairs tests.

Results The results showed that indices developed for Greece and Italy were not similarly correlated to sample scores along DCA axis 1. Species' indicator values for Italy and for Greece were highly significantly correlated for light and moisture and significantly correlated for temperature, but the correlations were weak ($0.20 \leq \text{gamma} \leq 0.31$). Pairwise testing gave significantly different indicator values for the two regions. Discrepancies below or equal to 2 units on 9-point scales (12 points for moisture) were found for 88%, 70% and 54% of the species respectively for light, temperature and moisture indices. A substantial number of species showed higher discrepancies, from 3 up to 6 units.

Main conclusions In the light of the present work, it seems clear that the indicator values developed for Italy and for Greece should not be used outside the region for which they were defined. This constitutes additional evidence that indicator values can be influenced by the identity of potential competitors. It also underlines the need to use standardized methods for calibrating indicator values against measured variables in such a way that indicator systems can serve as general reference systems.

Keywords

Calibration, ecological amplitude, ecological indices, Mediterranean Basin, regional scale, species' ecological response.

INTRODUCTION

Plant species are tightly constrained by the climatic regime under which, and the soil type on which, they grow. Plants often reflect temporally integrated environmental conditions and are therefore particularly useful indicators when values averaged over time are needed (ter Braak & Gremmen, 1987). In Europe, the indicator value approach has been used for many years. It is based upon the principle that individual plant species can be associated with a particular range of conditions, for example pH, site moisture and soil fertility, and on this basis can be given values denoting the position along

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environmental gradients at which each, on average, reaches peak abundance (Smart, 2000). The indicator species system of Ellenberg *et al.* (1991), which is one of the most widely used, describes the response of a species to edaphic and climatic parameters in comparison with other species. The authors of this data base placed each species on a 9- or 12-point ordinal scale according to its distribution with respect to light (L), temperature (T), continentality (K), moisture (F), reaction (R), and nitrogen (N). These indicator values are derived from observations of the field distributions of the species in central Europe and can therefore potentially act as surrogates for actual field measurements (Thompson *et al.*, 1993). Ellenberg's values apply to the overall ecological behaviour of the species in central Europe. The fact that species behaviour varies widely from one region to another suggests caution in the use of indicator values and their extrapolation to other regions (Pignatti *et al.*, 2001; Gégout & Krizova, 2003). However the applicability of Ellenberg's system in other areas has been confirmed by several authors (e.g. Persson, 1981; ter Braak & Gremmen, 1987; van der Maarel, 1993; Diekmann & Dupré, 1997; Koerner *et al.*, 1997; Diekmann, 2003). Even if some calibration has been proposed to extend the indicator values to new areas (Hill *et al.*, 1999, 2000; Lawesson *et al.*, 2003), it is considered that the values based on habitat preferences in central Europe are reasonable predictors of the ecology of western European (Thompson *et al.*, 1993) and northern European (Diekmann, 1995; Lawesson & Mark, 2000) populations of the same species. This extension westwards and northwards was possible thanks to the large number of species in common and to the relatively similar latitudinal distribution. A possible southward extension was much more problematic because of the few species shared by these two climatically different regions. Recently, Pignatti *et al.* (2001) on the one hand, and Böhling *et al.* (2002) on the other hand independently developed new data bases for the flora of southern Europe. They are the first to give a quantification of the field response of Mediterranean species to a range of climatic and edaphic factors. These works allow an important and considerable extension of the original Ellenberg system to an area not hitherto covered by such a databank, because they include many taxa not involved in the flora of central Europe. The aim of this paper is to explore the possibility of extending indicator systems through different Mediterranean areas. An attempt to correlate these two independent sets of data therefore constitutes a particularly severe test of the general usefulness of these values outside the areas for which they were defined. If, for common species of wide distribution, few or negligible differences between the indicator values of different Mediterranean areas are found, it could be expected that the extension of Ellenberg's indices is feasible, which would be of great utility in rapid landscape interpretation and management. The opposite result, the existence of significant differences between indicator values, would suggest that, contrary to central and northern European landscapes, an indicator system for the countries of the Mediterranean Basin would not be reliable, given the strong differences in ecological conditions and community patterns, and, consequently, the design of local or regional systems of assessment should be considered instead.

It is within this context that this article will attempt a detailed comparison of species indicator values in Italy (south-central Europe) and in Greece (south-eastern Europe), and, by analysis of the amplitude of discrepancies between the two data sets, evaluate the relevance of using these values in other areas in the Mediterranean Basin.

MATERIAL AND METHODS

We used systems of indicator values developed by Pignatti *et al.* (2001) and Böhling *et al.* (2002) for the Mediterranean region, in Italy and Greece, respectively. Both systems were developed according to Ellenberg's principles. Böhling *et al.* (2002) assigned, to 2442 taxa from southern Greece (a floristically homogenous region), ecological indicator values for seven environmental factors (light, temperature, continentality, moisture, soil reaction, nutrients and salt), based on vegetation relevés, measurements of environmental variables [relative irradiance, pH ($CaCl_2$), C/N, C/P] and existing ecological knowledge (mean annual temperature, phytogeographical continentality maps, landscape ecological water balance). In order to extend Ellenberg's model to the Italian flora, S. Pignatti and collaborators have been compiling a data base containing numerical indices for the same seven environmental factors for more than twenty years. In this data base, all the species of the Italian flora are reported, together with ecological and ecophysiological measurements for each species, if available. The complete list of indicator values referred to the Italian flora has not been published yet (L. Celesti, pers. comm.). For the purposes of this paper, we therefore worked on partial lists published by Pignatti *et al.* (2001), giving the ecological values for three environmental factors (light, temperature and moisture) for about 300 species reported from two locations from the Mediterranean part of Italy, namely the Inferno valley in Rome and Zannone Island (an island in the Tyrrhenian Sea off the west coast of Italy).

Each species that was mentioned in both references was taken into consideration in this study (after checking for synonyms). A global matrix containing 966 items of information (161 species × 3 indicator variables × 2 values assigned in each study, 1 for Italy and 1 for Greece) was constructed (Appendix S1). This data base included the ecological indicator values given by these authors for light, temperature and moisture factors, which are the focus herein.

In order to compare the ecological responses of species to the studied variables between the two regions, we performed indirect gradient analyses on 101 vegetation relevés from published phytosociological tables from the *Secalietea* class (Sanz-Elorza, 2001), using the ordination program Detrended Correspondence Analysis (DCA; Hill & Gauch, 1980) with the statistical package CANOCO 4.5 for Windows (ter Braak & Šmilauer, 2002). Eigenvalues for the first two axes of the ordination were 0.866 and 0.787. As DCA axes 1 and 2 explained most of the variation in the data sets, only these axes were considered for further analysis. The length of the gradient along the first axis was 8.207, indicating a variation in the species data set that is sufficiently high for the purposes of the analysis. We subsequently correlated the weighted averages (mL, mT and mF) according to Diekmann & Falkengren-Grerup (1998) of the indicator values for each sample in the two regions with the sample-plot score of the first two ordination axes. This provides us with a test of the accuracy of the values in predicting actual environmental conditions, and a better indication of their applicability. As the sample and species scores were regularly spread along the axes of the ordination diagram without showing distinct clusters, the relationships between sample scores and the weighted averages of the Ellenberg values were analysed by means of linear regressions (Diekmann & Falkengren-Grerup, 1998).

In a second step, to detect relationships in ecological indicator values between the two regions, the gamma statistic was used, because the data contain many tied observations. Gamma is basically equivalent to Kendall's tau, except that ties are explicitly taken into account (Statsoft Inc., 2001). Then, pairs of indicator values given for each species were compared using the Wilcoxon matched pairs tests (Zar, 1984). These statistical analyses were carried out with Statistica Version 6.0 (Statsoft Inc., 2001). The 0.05 error level was accepted as a significance threshold. All the statistical tests were nonparametric, given that the frequency of species indicator values did not follow a normal distribution (Zar, 1984). Species nomenclature follows Pignatti *et al.* (2001) and Böhling *et al.* (2002).

RESULTS

Correlations of the weighted averages of the Ellenberg values with the corresponding sample scores along DCA axis 1 showed that light indices developed for Greece did not explain the floristic variation in the vegetation samples, while the Italian indices did (Fig. 1a; Table 1). Temperature indices developed in Italy were negatively correlated with sample scores along DCA axis 1, while the opposite pattern was found for the values for Greece (Fig. 1b; Table 1). Moisture indices for both Italy and Greece were positively correlated with the DCA scores, but slopes and intercepts were again very different from each other (Fig. 1c; Table 1).

Species' indicator values for Italy and for Greece (gamma statistic) were significantly correlated for light, moisture and temperature, but the correlations were weak ($0.20 \leq \text{gamma} \leq 0.31$) (Fig. 2).

The comparison of species' ecology between the two regions by means of a Wilcoxon matched pairs test showed that, for each ecological factor except temperature, species' indicator values were significantly different in Italy and in Greece (Table 2). For the light value, the vast majority of the species showed an optimum between $L = 7$ and 9 (Fig. 3a). This reflects the light-demanding character of most of the species analysed. Very few species were indifferent to light, in Italy as well as in Greece. Most of the species (141 or 88%) had $|L^{(G)}-L^{(I)}| \leq 2$. Species for which $L^{(G)}-L^{(I)} \geq 3$ were *Brachypodium distachyum* ($L^{(G)} = 6$, $L^{(I)} = 9$), *Carex otrubae* (6, 9) (where the names $L^{(G)}$ and $L^{(I)}$ have been omitted for brevity), *Juncus bufonius* (7, 4), *Lathyrus sphaericus* (5, 9), *Phytolacca americana* (6, 9), and *Rancunculus bulbosus* (4, 8).

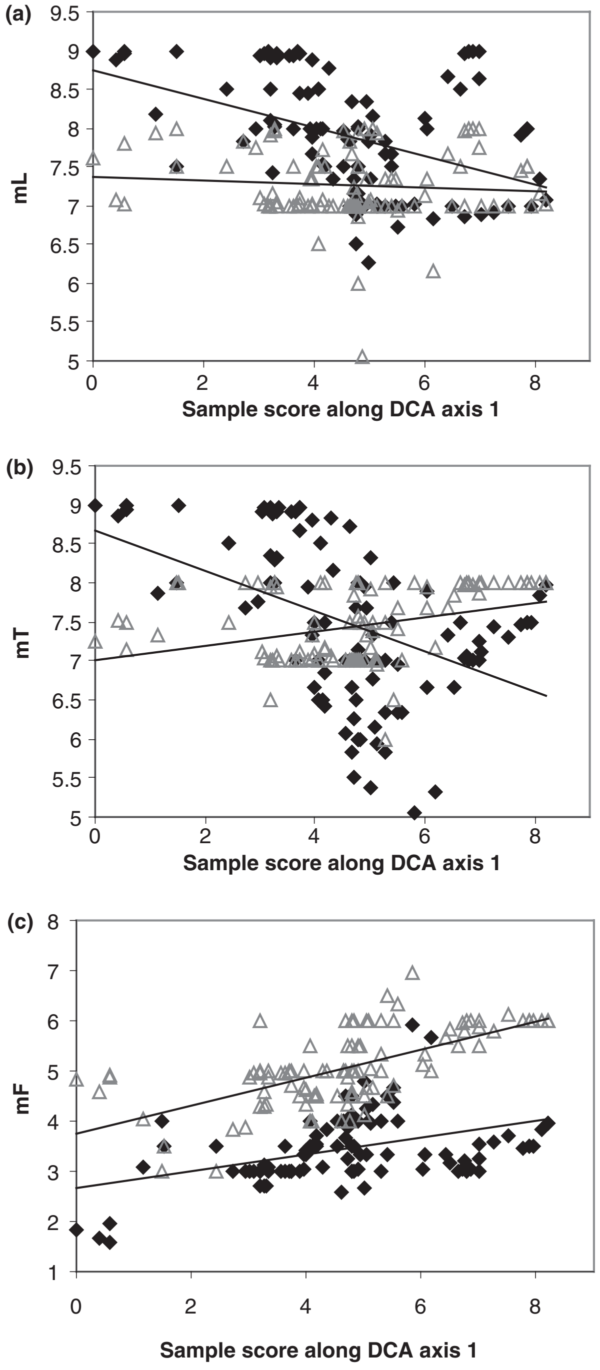

Figure 1 Relationships between weighted averages of Ellenberg indicator values for light (*mL*), temperature (*mT*) and moisture (*mF*) and the corresponding sample scores along DCA axis 1. (For regression parameters, see Table 1.) Diamonds: indicator values for Italy; triangles: indicator values for Greece.

For the temperature indices, most species had an indicator value between $T = 7$ and 9 (Fig. 3b). With the Greek values,

Table 1 Relationship between the sample score along DCA axes 1 and 2 and the mean Ellenberg indicator value for light (*mL*), temperature (*mT*) and moisture (*mF*). *n*: number of observations; *r*(s): Spearman correlation coefficient

	n	intercept	slope	*r*(s)	*P* level
DCA axis 1					
mL (Italy)	101	8.74	−0.18	−0.47	< 0.0001
mL (Greece)	101	7.36	−0.02	−0.10	0.3332
mT (Italy)	101	8.66	−0.26	−0.50	< 0.0001
mT (Greece)	99	7.01	0.09	0.32	0.0012
mF (Italy)	101	2.66	0.17	0.43	< 0.0001
mF (Greece)	99	3.74	0.28	0.67	< 0.0001
DCA axis 2					
mL (Italy)	101	7.65	0.05	0.15	0.1347
mL (Greece)	101	6.51	0.16	0.52	< 0.0001
mT (Italy)	101	8.14	−0.15	−0.21	0.0376
mT (Greece)	99	7.55	−0.02	−0.06	0.5446
mF (Italy)	101	3.26	0.04	0.11	0.2712
mF (Greece)	99	4.61	0.10	0.21	0.0373

38 species (26%) showed an index of $T = 9$, while with the Italian system only one species (0.7%) had this value. Twenty-four species were referred to as indifferent in Greece, while 16 species had this status in Italy, but none of them was referred to as indifferent in both data bases. Most of the species (112 or 70%) showed $T^{(G)}-T^{(I)} \leq |2|$. Species for which $T^{(G)}-T^{(I)} \geq 3$ were *Bromus fasciculatus* (8, 5), *Galium tricornutum* (8, 5), *Geranium columbinum* (5, 9), *Geranium dissectum* (6, 9), *Rumex crispus* (8, 5), *Sonchus asper* (8, 5), *Trifolium subterraneum* (6, 9), *Vulpia bromoides* (4, 9), and *Vulpia muralis* (6, 9).

The frequency distributions of moisture values were different in the two regions, indicating that species were generally judged to be more drought-tolerant in Italy than in Greece: 72 species (48%) were dry-site indicators ($F = 1$ to 3) in Italy, while only 23 species (16%) were judged as having the same ecological requirements in Greece (Fig. 3c), where the optimum was at $F = 5$ (39 species; 27%). Eleven species were indifferent in Italy, while the 15 indifferent species for Greece were spread along the whole moisture range according to the Italian system. There were 20 species (12%) having exactly the same indicator value in both regions, 56 species (35%) for which $|F^{(G)}-F^{(I)}| = 1$, 31 species (19%) showing $|F^{(G)}-F^{(I)}| = 2$, and 15 species (9%) having $|F^{(G)}-F^{(I)}| = 3$. The largest discrepancies were found for 13 species (8%) for which $|F^{(G)}-F^{(I)}| \geq 4$: *Bromus fasciculatus* (2, 6), *Bromus hordeaceus* (7, 2), *Carlina lanata* (2, 6), *Conyza albida* (7, 3), *Eleusine indica* (6, 2), *Fumana thymifolia* (2, 8), *Geranium dissectum* (7, 2), *Lathyrus annuus* (8, 3), *Medicago arabica* (7, 3), *Trifolium angustifolium* (6, 2), *Trifolium ligusticum* (7, 2), *Vulpia bromoides* (7, 2), and *Vulpia ligustica* (6, 2).

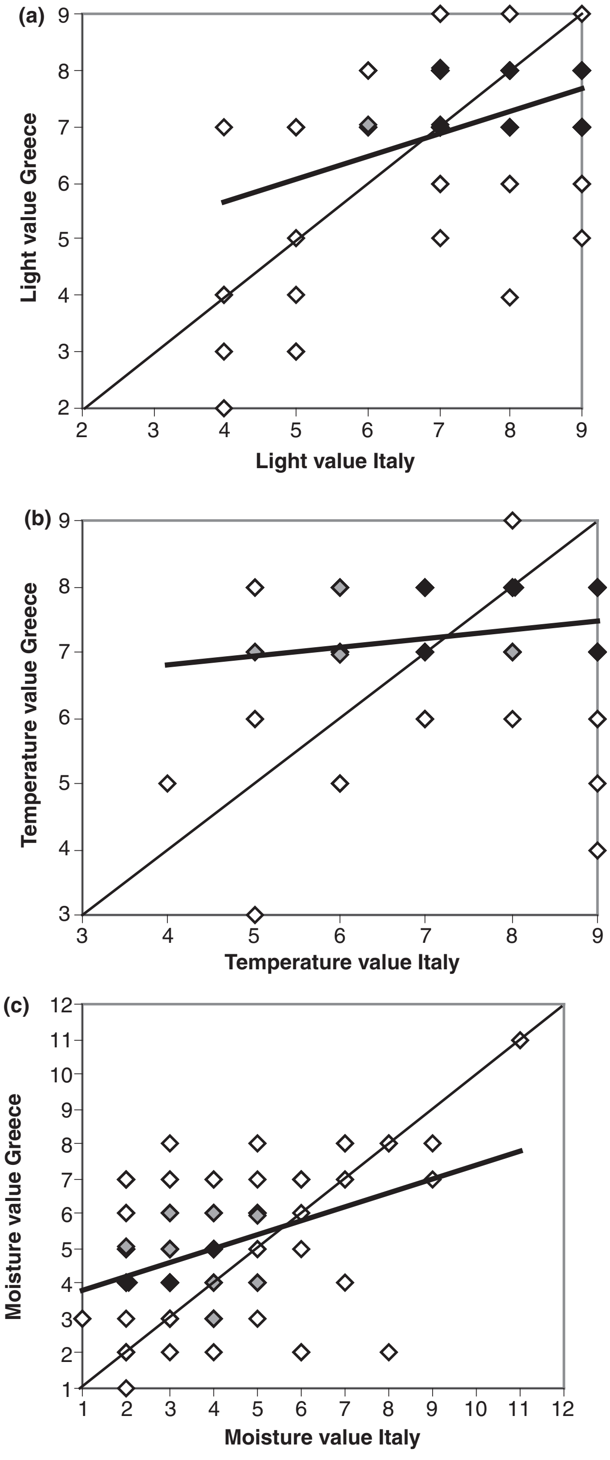

Figure 2 Relationships for indicator values between Greece and Italy. The line $y = x$ and the regression line are shown. (a) light ($n = 147$; gamma = 0.28; $z = 3.52$; $P = 0.0004$); indifferent species: 12 (Italy) and 2 (Greece); (b) temperature ($n = 121$; gamma = 0.20; $z = 2.27$; $P = 0.0232$); indifferent species: 16 (Italy) and 24 (Greece); (c) moisture ($n = 135$; gamma = 0.3085; $z = 4.39$; $P < 0.0001$); indifferent species: 11 (Italy) and 15 (Greece). White diamonds: fewer than 5 observations; grey diamonds: 5 to 10 observations; black diamonds: more than 10 observations.

DISCUSSION

This paper is the first comparative study dealing with Ellenberg indicator values for Mediterranean plant species. Our study

Table 2 Wilcoxon matched pairs tests for species indicator values in Italy and in Greece

	Mean (Italy)	SD	Mean (Greece)	SD	*n*	*z*	*P*
Light (*L*)	7.62	1.31	7.06	1.19	147	4.36	< 0.0001
Temperature (*T*)	7.28	1.40	7.22	0.99	121	0.43	0.6614
Moisture (*F*)	3.82	1.74	4.92	1.60	135	6.33	< 0.0001

identifies potential discrepancies between two independent indicator value systems developed for Italy by Pignatti *et al.* (2001) and for Greece by Böhling *et al.* (2002). Although statistically significant relationships were found between the two data sets, the rank correlations showed a large spread (0.20 ≤ gamma ≤ 0.31). Moreover, when considering pairwise testing, the results gave significantly different indicator values for the two regions. In order to compare these results with other data bases, we made a correlation between the original Ellenberg values for central Europe (Ellenberg *et al.*, 1991) and those developed for the British countryside (Hill *et al.*, 1999) by taking a subset of 400 species common to both species lists. We found highly significant relationships between the two species lists, with correlation coefficients between 0.73 and 0.87, which is much higher than when comparing the two Mediterranean data sets. The results raise the question why the same amplitude of discrepancies was not found when comparing subsets of the two data bases from central Europe and Great Britain. One possible explanation could be that, in contrast to Böhling *et al.* (2002) and Pignatti *et al.* (2001), who developed indicator values based on measurements independently from each other, Hill *et al.* (1999) calculated new values by comparing the original indicator values of species with the mean values of their associated species. The resulting inertia may explain the closer correspondence.

The magnitude of discrepancies between the Italian and Greeks data bases can be attributed to a number of causes.

Geographical shifts in species behaviour and strong environmental gradients

Species are not always constant in their ecological requirements and should in principle have different indicator values in different parts of their range (Hill *et al.*, 1999, 2000). The different behaviour of species in the two areas is made apparent essentially by two phenomena: first, species were found to be more hygrophilous in Greece (although this is not absolutely certain, given the apparently different range definitions), and second, they were more heliophilous and xerophilous in Italy. On the other hand, Ellenberg's system has been successfully extended to different areas of central and northern Europe, which may exhibit comparatively weaker environmental gradients than those shown by Mediterranean countries. The existence of significant differences between indicator values for Italy and Greece suggests that, in contrast to the case for central and northern European landscapes, a global indicator system for the countries of the Mediterranean Basin would not be reliable, given the strong environmental gradients. Consequently, the design of local or regional systems should be considered instead.

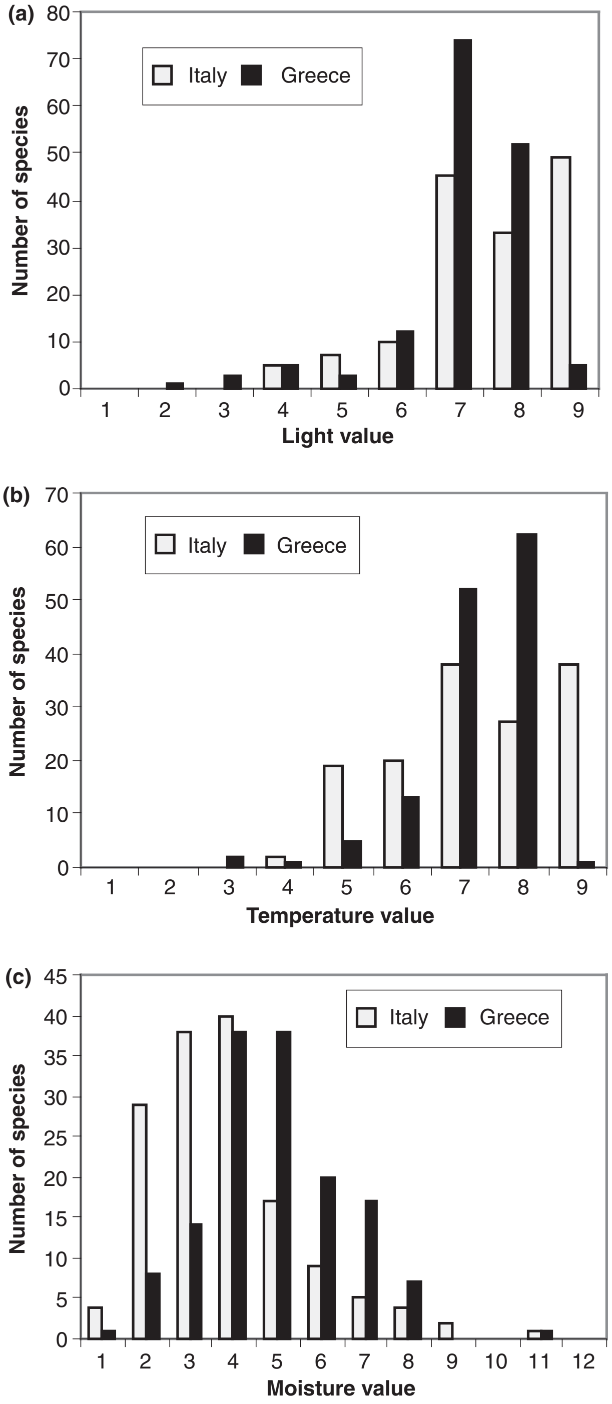

Figure 3 Distribution of species indicator values in Italy (grey bars) and in Greece (black bars). Tests of significance are given in Table 2.

Scale and definition of classes

Both the scale and definition of classes may be different from one author to the next. In the case of the temperature values, Pignatti's scale consists of 12 points (rather than 9), because of the warmer climate in the Mediterranean region compared with central Europe. However, this scale is just an expansion of Ellenberg's, in that three more values were added for the thermophilic taxa (but not actually assigned to any species from the subset taken into consideration in this study). Similarly, the scale of indicated moisture covers 12 classes, like Ellenberg's, but Böhling *et al.* (2002) expanded it by an additional value '0' to reflect the pronounced aridity in southern Greece (also not assigned to any species from the subset taken into consideration in this study).

Competition effects

Competitive relationships between species change according to the presence or absence of potential competitors (Diekmann & Lawesson, 1999). Hence, the optimal ecological requirements of a species when in competition with other species can vary from region to region (Pignatti *et al.*, 2001).

Climatic differences between regions

Species can change their habitat as a compensation for differences in climate, thereby keeping within similar environmental conditions (Diekmann & Lawesson, 1999). Even within the Mediterranean region, climatic differences can be substantial. Mean daily temperatures for Rome (Italy) and Kalamata (southern Greece) (both lying in the middle of the regions of interest) differ between 1.8°C and 3.3°C (Lieth *et al.*, 1999). Although mean annual precipitation values are the same, mean monthly precipitation during the summer is three to four times higher in Rome than in Kalamata. This can account for shifts along temperature, light and moisture gradients.

Genetic differentiation of ecotypes

Species fundamental niches can also vary if ecotypes are differentiated. This implies changes in physiological demands, which in turn affect the ecological behaviour (Diekmann & Lawesson, 1999).

Selection of species and habitat types

The analyses were performed on a sample of only 161 species (corresponding to the data published so far and common to both data sets), which represents a low percentage of the floras of the regions considered. Furthermore, most of these species are ruderals characterizing disturbed habitats, belonging mainly to the *Secalietea* and the *Artemisietea* phytosociological classes. Other ecological groups are poorly represented in the data set. Wetland species, for instance, are virtually lacking in the analysis. The inclusion of this species group would probably improve the correspondence between the systems. Wetlands are indeed azonal vegetation types, which means that species composing this biotope are more dependent on specific soil conditions than on climate.

The results obtained here support the idea that the development and subsequent application of Ellenberg values is viable on a local scale, at most. It therefore seems clear that the species indicator values developed for Italy and for Greece should not be used outside the region for which they were defined. This strongly limits the application range of these indicator values at broad scales. We therefore recommend the calibration of these values for other Mediterranean areas against measured abiotic variables. Another approach would be to use only those species having the same values in Italy as in Greece, the disadvantage being that analyses would then depend upon a smaller array of these species. Moreover, the calibration of such expert systems requires the coordination of methods, criteria and scales (Hill *et al.*, 2000).

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SUPPLEMENTARY MATERIAL

The following supplementary material is available for this article online from http://www.blackwell-synergy.com:

Appendix S1 Ellenberg's indicator values from the two data bases as used in the analyses.

BIOSKETCHES

Sandrine Godefroid works as a postdoctoral researcher at the University of Brussels (VUB), in the Research Group of General Botany and Nature Management. Her main research is within the field of plant ecology applied to the study of relationships between nature management practices and the vegetation development in temperate forests, wetlands, heathlands, and in urban ecosystems.

Elías Dana is an associate professor in the Department of Plant Biology & Ecology of the University of Almería. For about 10 years, his research has concentrated on the study of functional aspects of disturbed ecosystems, with special emphasis on the ecology of invasions and urban ecology. In the last 6 to 7 years, he has worked on the analysis of invasion patterns of Mediterranean plant species, especially from the autecological point of view.

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