



Validation of phytosociological classifications based on a fuzzy set approach

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Abstract: We propose a simple method to validate vegetation types in phytosociological tables obtained with the Braun-Blanquet approach. The method is based on fuzzy set theory and it measures the sharpness of a classification of relevés based on degrees of belonging calculated by similarity functions. The idea animating this work is that the validated vegetation types offer non-random species combinations that can be used to model environmental changes taking biodiversity into account. Phytosociological tables are widely available today and the information they contain can be very useful in studying environmental changes at different scales, from local to global.

Introduction

The definition of vegetation types, both to study vegetation processes and for practical cartographic representation (e.g., Küchler and Zonneveld 1988, Blasi et al. 2000) is becoming more and more relevant in the light of worldwide recognition of the importance of vegetation in relation to global change (Anand and Orlóci 1997, Orlóci 2001ab, Orlóci et al. 2002ab, Hannah et al. 2002, van der Maarel 2004). Biondi et al. (2004) have shown how vegetation types can be used to measure the response of vegetation to environmental gradients, offering a powerful synthetic way to describe vegetation variation based on fuzzy set theory. This new perspective, introduced by Andreucci et al. (2000), is a further reason to work in the direction of understanding the nature of plant communities and to find a way to achieve useful classifications of vegetation at different hierarchical levels. Several databases are already available, constituting very important tools for studies of vegetation variation as a function of space and time (Mirkin 1987, Pignatti 1990, Rodwell et al. 1995, Mucina 1997, Solomeshch and Mirkin 1999, Rivas-Martínez et al. 2001, 2002). However, these data bases are not used as they could be in environmental studies necessary for environmental management and biodiversity conservation. The reason is that the floristic approach, formalized by Braun-Blanquet (1964) (see Mueller Dombois and Ellenberg 1974, van der Maarel

1975, 1981, Westhoff and van der Maarel 1978, Mucina and van der Maarel 1989, Mucina and Dale 1989, Mucina 1997) is still misunderstood and neglected even in the circles of vegetation scientists. This may be a personal view; however, it finds support when one considers the small number of papers based on the Braun-Blanquet approach that are published in international journals, and how the topic is neglected in recent books of vegetation ecology and landscape ecology. It is surprising that even van der Maarel's book (2004) does not include a specific chapter on the usefulness of syntaxonomy in the ecological study of vegetation. We are conscious that several criticisms of the Braun-Blanquet approach are consequences of "difficult" Latin names for the vegetation types, of the fact that the vegetation patches to be used for relevés should be uniform, but that this uniformity is assessed only subjectively and of the fact that the European phytosociologists invested much of their effort in nomenclatural problems related to syntaxonomy, rather than in showing the usefulness of their method with concrete examples in the most popular international ecological journals. However, we are also convinced that ecological studies on vegetation have limited relevance if they lack a reference system. One needs to see the syntaxonomical system as a framework with operational value and not as a dogmatic paradigm (Mucina and van der Maarel 1989). From palaeoecology (e.g., Roy et al. 1996, Stafford et al. 1999)

one knows that in the past different assemblages of plant species and animals were present and that the world has been subjected to continuous biological dynamics, but this knowledge could not devalue the classification of present-day “plant assemblages” found and described in homogeneous environments (plant communities). We would not even like to insist on calling them “plant communities”, in order to avoid further stimulating the debate whether they exist or not (Dale 1994, Mirkin 1994, Palmer and White 1994, Wilson 1994, Wilson et al. 1995). It is logical that the majority of plant species move individually to colonise new areas (Hannah et al. 2002), since there are no “special collective transportation tools” arranged for the species living in “plant assemblages”. However, this is not an argument against the existence of plant communities and against their classification into vegetation types from the association (and down: sub-associations and variants) to higher hierarchical syntaxa. The fact that plant communities rarely have clear boundaries does not mean that they cannot be interpreted as distinguishable objects which can be classified and ordered (van der Maarel 2004, Austin 2004).

We think that the framework proposed by syntaxonomy is a useful operational reference system, far superior to other systems based on structural and bio-geographical characters only. Certainly this sentence may cause some irritation among vegetation ecologists who still interpret “continuum theory” as a conceptual tool, arguing against the existence of plant communities. The superiority of syntaxonomy relies on the fact that the syntaxonomical framework retains information on the floristic composition of plant communities, which is highly relevant when one is studying biodiversity in an ecosystem perspective. In this respect, Feoli (1984) has shown how it is possible to derive structural and bio-geographical multidimensional spaces from floristic vegetation tables in order to make comparisons of vegetation types from different bio-geographical areas.

Many numerical methods can be used to classify relevés (Mueller Dombois and Ellenberg 1974, Orlóci 1978, Westhoff and Maarel 1978, Jongman et al. 1995, Legendre and Legendre 1998, Podani 2000, Wallace and Dale 2005); however, as was stressed by Pillar (1999), all these methods have a certain component of subjectivity. For this reason, we think it is not useful to test all possible classifications, but that it is more relevant to study the similarity pattern of the set of relevés of a classification using different similarity measures. The knowledge and experience of the researcher always determine the final classification of vegetation at different hierarchical levels (Mucina and van der Maarel 1989). Unfortunately, many

vegetation ecologists who do not understand or accept the operational meaning of the plant community and the “association” concept, consider this aspect a further drawback of the Braun-Blanquet approach. However in this paper we hope to give further support to the Braun-Blanquet approach, by showing how one can use phytosociological tables to challenge proposed syntaxonomical classifications. We do not think that classifications proposed by phytosociologists need to be repeated using numerical methods. We simply propose a method of clarifying the relationships between vegetation types in terms of their floristic similarity. The exercise is useful also to extract information on the biology and ecology of the species and plant communities of a given geographic area. For this purpose we use a data set that we think is particularly suitable, namely weed vegetation, in which variation between different plant communities is very gradual and strongly recalls the “continuum theory” (Austin 1985, Austin and Smith 1989), the ecological situation being highly dynamic and influenced strongly by human impact.

Data

This study is based on relevés of weed vegetation of wheat, oats and barley fields in Molise (Central Italy), recorded by Ferro et al. (1997). The data matrix used for the study has in total 43 relevés and 225 species. The scores in the matrix are the percent cover of species as recorded in the field and not transformed according to the Braun-Blanquet scale (Braun-Blanquet 1964). The table is structured in two main associations based on the experience of Ferro and his colleagues; however, they have also used a numerical method to improve the presentation of the phytosociological table, so that similar relevés are placed beside one another in the table. The first association is *Ornithogalo brevistyli-Biforetum testiculatae*, with relevés from hills facing the coast, at altitudes between 60 and about 800 m. This association belongs to the alliance *Romerion hybridae* Br.-Bl. ex Rivas-Mart., Fern.-Gonz. & Loidi 1999 (synonymous *Secalio cerealis* Br.-Bl. in Br.-Bl., Gajew., Wrab. Et Wal. 1936). The second association is *Knautio integrifoliae-Anthemidetum triumfetti*, with relevés from the mountain area at altitudes between about 800 and 1000 m, belonging to the alliance *Caulidion lappulae* R. Tx. ex von Roch. 1951 (synonymous *C. platycarpi* R. Tx. 1950). Both the alliances belong to the order *Centaureetalia cyani* R.Tx. ex von Roch. 1951 (synonymous *Secalietalia cerealis* Br.-Bl in Br.-Bl., Gajew. & Walas 1936).

Within the *Ornithogalo brevistyli-Biforetum testiculatae*, three vegetation sub-types have been distinguished.

Table 1. Concentration values (%) of the submatrices (blocks) formed by species groups in vegetation types in the matrix species by relevés.

		Vegetation types							totals
		a	b1	b2	b3	c	e	f	
n.rel.		3	11	7	2	3	4	10	40
n.sp.		30	69	85	55	59	72	76	
Species groups	1 18	0	24	25	16	20	24	16	125
	2 19	2	13	19	10	12	12	3	71
	3 17	0	9	10	3	8	10	39	79
	4 18	2	1	2	0	0	1	26	32
	5 13	15	17	9	15	10	13	2	81
	6 19	2	13	20	11	21	42	24	133
	7 20	3	13	26	28	12	18	16	116
	8 21	3	9	18	19	11	32	14	106
	9 14	26	17	16	32	12	16	14	133
	10 19	4	4	8	5	30	8	6	65
	11 13	15	11	23	27	13	12	12	113
	12 8	17	15	14	37	4	3	1	91
	13 10	17	20	17	5	17	10	7	93
	14 16	3	19	19	9	52	17	19	138
totals 225		109	185	226	217	222	218	199	1376

One (here called “a”, “assemblage with *Fallopia convolvulus* and *Avena sterilis*”, with 3 relevés) occurs in wheat fields treated recently with chemical weed-killers. The other two correspond respectively to a phase called initial, because the chemical treatments took place only two or three years before the relevés (“b1”, with 11 relevés), and to a phase called optimal or mature (“b2”, 7 relevés), where chemical treatments were performed more than 4 years before the relevés, or never. Incidentally, such relevés have an average altitude higher than those of the type b1. These subtypes have not been given a Latin name since Ferro and his colleagues regarded them as representing just two “variants” of the same association, reflecting the time since chemical weed-killer treatments were applied.

Within the association *Knautia integrifoliae-Anthemidetum triumfetti* (here designated “f”, with 10 relevés) no subtypes were distinguished. A transition type between the two associations was recognised (“e”, with 4 relevés). Furthermore, Ferro et al. (1997) identified one vegetation type, called “grasslands”, with two subtypes (“b3” with two relevés, and “c” with 3 relevés) covering fields left uncultivated (we will call this type “b3∪c”, with ∪ meaning union). Three relevés (“d”, “g” and “h”) do not belong to any vegetation types.

To test whether the classification proposed by Ferro et al (1997) is significantly sharp we have applied the permutation method proposed by Pillar and Orlóci (1996).

The classification was shown to be significantly sharp ($p = 0.002$); but other classifications of the same data set obtained by cluster analysis also showed the same significance. In order to understand the data structure of the phytosociological table better, using correlation coefficients among the species, and by cluster analysis using average linkage within merged groups (Podani 2000) 14 species groups were identified. The data matrix, structured according to the species groups, has been reduced by calculating the concentration values (% of cells occupied by scores in the blocks, see Feoli and Orlóci 1979). The reduced matrix showing the concentration values in the blocks (14 species groups × 7 vegetation types: a, b1, b2, b3, c, e and f) is presented in Table 1. In this table only one block has a concentration value higher than 50%; the others have relatively low values, indicating that the blocks are sparse sub-matrices. Thus, the vegetation types are not strongly characterized by species groups; only the vegetation types c, e and f have some outstanding concentrations in the blocks (species groups 3, 4, 6, 8, 10, 12, 14). This means that characterisation of the vegetation types is difficult; consequently, the data set chosen is particularly suitable for the exercise we are proposing.

Methods

According to set theory, any “character” or “proposition” (e.g., a statement such as: “the elements that are moving”) defines two sets of elements: the set of elements having the character (or satisfying the proposition) and

the set of elements without the character (i.e., the complementary set). The study of complex systems, such as vegetation, often uses classification algorithms (classification approach, Pausas and Feoli 1996) to partition sets into subsets and/or generate new descriptions of the elements of the sets using external variables. The present aim is to understand the structure and functioning of vegetation systems (Feoli 1984, Feoli and Orlóci 1991). The elements of the sets in vegetation study are areas of land covered by vegetation. In the Braun-Blanquet approach when they are sampled and described according to an established procedure they are called *relevés* (Mueller Dombois and Ellenberg 1974, Westhoff and van der Maarel 1978). The definition of different subsets within the same set of elements using different sets of variables is an important step in finding the correlation between the sets of variables. If there are two sets of variables A and B for the same set of objects and one wishes to estimate the overall correlation between them, a way to obtain a measure of such a correlation is by calculating the intersection between the subset of objects defined by variable set A and the subset of objects defined by variable set B. These subsets (clusters) can be obtained by cluster analysis or other classification methods (Feoli and Orlóci 1991). The larger the intersection the higher is the correlation. Another way, besides classical canonical correlation analysis, is to measure the sharpness of the classification obtained with the variables of A by using the variables of B and vice versa. Pausas and Feoli (1996) use canonical discriminant analysis for this purpose (Orlóci 1978, Legendre and Legendre 1998, Podani 2000), whereas Pillar and Orlóci (1996) suggest using permutation tests as an alternative to parametric tests (e.g., canonical variates analysis). Yet another way is to correlate the distance or similarity matrices of objects obtained respectively using variable set A and variable set B with Mantel's test and full randomisation tests (Tobisch and Standovár 2005).

In this paper, we propose a method that uses measurement of the sharpness of vegetation types, as described in phytosociological tables, with similarity functions. The method actually finds the correlation between the set of "variables" used by a phytosociologist in defining the vegetation types, let us call it A, and the set of species in the phytosociological tables (set B). Usually the set A may have many variables that are not measurable (e.g., knowledge of the ecology and geographical distribution of each species, knowledge of the effects of environmental heterogeneity on the species distribution, etc.). These variables all belong to the knowledge base of the phytosociologist, and are involved in his final decision in defining the vegetation types. Set B is that on which the phytosociologist focuses measurements, namely the

names of species and their cover value. There is redundancy between sets A and B because phytosociologists always also take into consideration the set B when they propose a classification of vegetation. We can therefore say that B is included in A, finding the similarity functions that best simulate the classification of a phytosociologist, means to quantify with a similarity function his knowledge-based approach.

We use similarity matrices not to produce clusters, as happens in cluster analysis, but to calculate the "degree of belonging" of *relevés* to vegetation types established by the phytosociologists. The method we are proposing uses fuzzy set theory (Cox 1994, Zimmerman 1996), introduced in vegetation studies independently by Roberts (1986), and Feoli and Zuccarello (1986).

The objective is to find the similarity function that best fits a proposed classification of *relevés* and to analyse the "stability" of the proposed types in order to suggest the optimal number of types in a phytosociological table. The term stability here means the constancy of *relevés* membership to clusters irrespective the method used for classification.

When one assigns a *relevé* (x_i) to a type (set X_j), it is always allotted a measure in a nominal scale (the name of vegetation type). Given a phytosociological table with n *relevés* assigned to k vegetation types, the method calculates the similarity between the n *relevés* using different similarity functions. Therefore, for each similarity function, a similarity matrix $n \times n$ is available. With this matrix, the "degrees of belonging" of *relevé* x_i to each of k vegetation types are calculated. By analogy with single, complete and average linkage clustering methods, one can use respectively one of the following criteria:

- the maximal similarity with one of the *relevés* in each of the k sets;
- the minimal similarity with one of the *relevés* in each of the k sets;
- the average similarity with the *relevés* of the k sets.

In the present study, we define "degree of belonging" as the average similarity. After computing the "degree of belonging" for each *relevé*, using the $n \times n$ similarity matrix, we obtain a fuzzy matrix of $n \times k$, with k fuzzy sets. To measure the sharpness (S) of the classification we suggest:

$$S = \frac{\sum_{j=1}^k m_j}{n} \quad (1)$$

where m_j is equal to the number of maximal degrees of belonging (in this case average similarity values) that the relevés of the type j have in the fuzzy set j . S ranges between 0 and 1.

The ratio

$$s_j = \frac{m_j}{n_j} \quad (2)$$

with n_j equal to the number of relevés in type j , is a measure of vegetation-type “stability”. If the “degree of belonging” of all the relevés assigned to a vegetation type is maximal for that vegetation type the classification is stable. The stability decreases if the relevés assigned to a vegetation type have higher “degrees of belonging” to other vegetation types.

The similarity function for which S is the highest is the one that best reproduces the mental processes of the phytosociologist in producing the classification. The similarity function, for which s_j is the highest is the one that best reproduces the mental processes of a phytosociologist in defining the vegetation type j . One should understand that phytosociologists do not always follow the same criteria in giving weight to the variables involved in “matrix A” (i.e., the set representing their knowledge data-base).

Various similarity functions may be used to calculate the similarity matrix $n \times n$ (Sneath and Sokal 1973, Orlóci 1978, Dale 1988, Podani 1995, 2000) and one can even invent new ones. Podani (2005) discusses a new one for ordinal data. We use only four of them as representative of the possible strategies followed in classifying the set of relevés in a syntaxonomical study.

For the purpose of this work, we distinguish two main types of similarity functions:

- Invariant ones, that always give the same similarity value for two objects independently of the data set in which they are considered, and
- Contextual ones, that may give different similarity values for two objects depending on the data set within which they are considered.

The first type includes all the simple matching similarity functions that are frequently applied in vegetation studies (Euclidean distance, cosine index and different scalar products centred or normalized, etc.; see Podani 2000). The second type includes probabilistic-based similarity functions such as the Goodall’s index (Goodall 1964, 1966, 1993), the index proposed by Burnaby (1970) (see Carranza et al. 1998) and COCHIS (Feoli and Lagonegro 1983). All these similarity functions treat

mixed data (data measured in different scales, nominal binary, ordinal and interval-ratio), however in the present study they are applied to ratio scale since we use the percentage cover of the species. Since the phytosociologists always work in a certain context, we think it more appropriate to use contextual similarity for simulating the phytosociologist’s classification.

In the present work we have applied one similarity function of the first type, namely the cosine index and three of the second type, namely the Goodall index with the program SIMILC (Goodall et al. 1987, 1991), and the Burnaby index and the index COCHIS, with the program BURNY-COCHIS (Carranza et al. 1998).

In the functions of the first type, the species have the same weight, while in the similarity functions of the second type they get different weight. In the indices of Burnaby and COCHIS, the weight depends to the association between species, while in the case of the Goodall index it depends only on the frequency of the species. The Goodall index considers the species as independent and gives greater weight to rare species, therefore the co-occurrence of rare species is important in defining the similarity between two relevés. SIMILC combines the similarity of relevés on the basis of presence/absence data and quantitative scores where the species is present (Goodall and Feoli 1988). In the Burnaby index, the user may choose to weight for species association or for species independence; the rare species have automatically high weight. COCHIS gives weight to species association irrespective of their frequency. Both the Burnaby and COCHIS indices measure the association in terms of correlation or chi-square. In our case, since the variables are measured on the ratio scale, association is measured by the probability of the correlation coefficient. COCHIS requires in input, for quantitative data only, a threshold indicating how similar the cover values of species shared by two relevés must be in order to contribute to their similarity. In our case we have set the threshold at 30% – in other words, a species contributes to the similarity between two relevés if in one relevé its cover value is not less than 30% of the cover in the other relevé. We applied the method to test:

- which similarity function best validates the classification of Ferro et al. (1997),
- whether the subtypes of *Ornithogalo brevistyli-Bi-foratum testiculatae* (a, b1, b2) are distinguishable in terms of similarity, in accordance with the principle of “Occam’s razor” — not recognising more sets than necessary (see Wallace and Dale 2005),

- to which vegetation types the isolated relevés (d, g, h) are more likely to belong.

Results

Table 2 presents the S values for each similarity function, the stability (s_j) of each vegetation type suggested by Ferro et al. (1997), and to which vegetation types the relevés d, g and h are assigned.

On the basis of the S values, the Goodall index shows the highest sharpness, while the cosine index shows the least. Among the options of the Burnaby index, the one weighting independence is the weaker in justifying the vegetation types proposed by Ferro et al. (1997). This means that Ferro et al. (1997) have used a contextual approach in defining the vegetation types and that they have given high weight to the co-occurrence of rare species (S high for the Goodall index) and to species associations (S high for the Burnaby index giving weight to association). Table 2 suggests that there is at least one similarity function supporting a vegetation type. However, it suggests also that on the average the types a, b1, b2 and e are “weak” (unstable).

If one considers $s_j = 0.60$ a good threshold for vegetation-type stability, from the table one can see that type a is validated only by the cosine index and the Goodall index. According to the other functions, the relevés of type a are all assigned to vegetation types b1, b2 or b3Uc, supporting the suggestion of Ferro et al. (1997) that type a is an impoverished aspect of *Ornithogalo brevistyli-Biforetum testiculatae*, produced by the application of chemical weed killers. The types b1 and b2 are supported respectively by the Burnaby index weighting association and by the Goodall index. This means that the floristic similarity within b1 is very low and that the association between some few species considered characteristic is responsible

for the recognition of the type. The fact that s_j is higher for the Goodall index in type b2 suggests that the floristic similarity within this type is determined by rare species. The situation of high floristic similarity in type a, and low floristic similarity in types b1 and b2, may be due to the effects of chemical treatments. In type a, they have drastically reduced the number of species (only 30 species, see Table 1), while the heterogeneity of type b1 and b2 may be a consequence of a non-regular process of recovery after the treatments. Actually, all the similarity functions except the cosine index support the type b3Uc (grasslands) that is no longer affected by chemical treatments. The same happens also for vegetation type f, which is free of chemical treatments. The vegetation type e, considered a transition vegetation type between the two main associations, is stable only with the cosine index. This means that the similarity between the relevés of this type is high, but depends on species that are not associated, as the results of the Burnaby index and COCHIS suggest.

According to these results, a classification with three vegetation types only, including a vegetation type aUb1Ub2 (*Ornithogalo brevistyli-Biforetum testiculatae*), the type b3Uc (grasslands) and the type f (*Knautia integrifoliae-Anthemidetum triumfetti*), could be enough if one wishes to follow the Occam’s razor principle. Considering this classification and leaving out the vegetation type e, which is considered transitional, the S values are 0.78 for the cosine index, 0.92 for the Goodall index, 0.78 for the Burnaby index weighting association, 0.58 for the Burnaby index weighting independence, and 0.92 for COCHIS. Both the Burnaby index options identify perfectly the type b3Uc.

The degrees of belonging according to the similarity functions that best validate the classification in three vegetation types (the Goodall index and the Burnaby index giving weight to association) are listed in Table 3.

Table 2. Stability of the vegetation types (s_j) and sharpness of the classification proposed by Ferro et al. 1997) according to S . The vegetation types to which the relevés d, g, h are assigned are indicated.

n. of relevés	S	Vegetation types						d	g	h
		a	bl	b2	b3Uc	e	f			
		3	11	7	5	4	10			
Cosine index	0.35	1	0	0.14	0.4	0.75	0.6	b1	f	e
Goodall index	0.67	1	0.18	0.71	1	0.5	1	b3Uc	fUb3	c
Burnaby index weighting association	0.57	0	0.64	0.14	1	0.2	0.9	eUb3	c/f	f
Burnaby index weighting independence	0.53	0	0.54	0	1	0.5	0.8	e	b3Uc	f
COCHIS	0.5	0	0.54	0.14	0.6	0	1	b3Uc	f	f

Table 3. Degrees of belonging of the relevés to the three main vegetation types (fuzzy sets) proposed by Ferro et al. (1997), according to the Goodall index and the Burnaby index with weight to association.

Rel.	Veg. types	Similarity Function					
		Goodall			Burnaby w. association		
		a∪b1∪b2	b3∪c	f	a∪b1∪b2	b3∪c	f
1	a	0.93	0.11	0.34	0.62	0.55	0.59
2	a	0.95	0.50	0.30	0.62	0.57	0.60
3	a	0.96	0.21	0.27	0.58	0.58	0.55
4	b1	0.90	0.90	0.31	0.61	0.59	0.57
5	b1	0.67	0.50	0.45	0.63	0.57	0.60
6	b1	0.84	0.91	0.27	0.59	0.53	0.59
7	b1	0.66	0.62	0.28	0.64	0.63	0.63
8	b1	0.62	0.66	0.28	0.66	0.65	0.61
9	b1	0.93	0.35	0.26	0.60	0.56	0.56
10	b1	0.80	0.53	0.25	0.59	0.55	0.55
11	b1	0.76	0.50	0.61	0.70	0.72	0.68
12	b1	0.69	0.59	0.27	0.66	0.63	0.60
13	b1	0.75	0.31	0.41	0.67	0.64	0.62
14	b1	0.98	0.18	0.30	0.62	0.60	0.60
15	b2	0.94	0.98	0.27	0.59	0.60	0.58
16	b2	0.69	0.68	0.52	0.61	0.60	0.62
17	b2	0.74	0.37	0.62	0.69	0.64	0.65
18	b2	0.75	0.39	0.42	0.56	0.56	0.54
19	b2	0.84	0.45	0.43	0.65	0.63	0.63
20	b2	0.71	0.27	0.33	0.53	0.52	0.50
21	b2	0.77	0.59	0.44	0.58	0.59	0.58
22	b3	0.66	0.84	0.12	0.61	0.65	0.61
23	b3	0.87	0.84	0.17	0.61	0.65	0.60
24	c	0.48	0.76	0.15	0.62	0.64	0.62
25	c	0.41	0.66	0.34	0.53	0.55	0.51
26	c	0.48	0.90	0.42	0.55	0.57	0.56
27	d	0.65	0.90	0.21	0.48	0.49	0.47
28	e	0.60	0.45	0.38	0.48	0.45	0.43
29	e	0.46	0.63	0.57	0.54	0.54	0.54
30	e	0.74	0.48	0.53	0.62	0.64	0.60
31	e	0.66	0.89	0.44	0.53	0.54	0.52
32	f	0.46	0.19	0.91	0.60	0.58	0.59
33	f	0.68	0.39	0.91	0.60	0.60	0.63
34	f	0.52	0.33	0.91	0.60	0.62	0.63
35	f	0.41	0.38	0.91	0.64	0.64	0.61
36	f	0.53	0.37	0.88	0.57	0.58	0.58
37	f	0.70	0.22	0.84	0.57	0.56	0.60
38	f	0.41	0.24	0.98	0.64	0.64	0.69
39	f	0.43	0.42	0.86	0.59	0.58	0.60
40	f	0.30	0.09	0.91	0.60	0.62	0.63
41	f	0.24	0.40	0.92	0.63	0.62	0.64
42	g	0.65	0.32	0.64	0.60	0.60	0.60
43	h	0.45	0.96	0.77	0.58	0.59	0.60

Some relevés have the same degree of belonging for more than one set. This means that they are really intermediate relevés. The scores in Table 3 may be useful in ordination of the relevés according to Feoli and Zuccarello (1986). The COCHIS scores are not presented because they are the same (0.50) for all the relevés of vegetation type f, and very low for all other relevés. This confirms the floristic heterogeneity of *Ornithogalo brevistyli-Biforetum testiculatae*, due both to chemical treatments and the dynamics of the plant communities. In this case, COCHIS was useful to validate the classification, but not for an ordination scattergram. This result is the consequence of the threshold we have set for similarity of cover values (see above, and Feoli and Lagonegro 1983). Figures 1 and 2

present ordinations of the relevés based on the fuzzy sets in Table 3, respectively for the Goodall index and for the Burnaby index. The three fuzzy sets in Figs 1 and 2 correspond to the two associations ($a \cup b1 \cup b2$, *Ornithogalo brevistyli-Biforetum testiculatae*; and f, *Knautio integrifoliae-Anthemidetum triumfetti*) and the grassland vegetation ($b3 \cup c$). The Figures show clearly that in this case the resolving power of the Goodall index is superior to that of the Burnaby index. The relevés of the three sets appear well separated in Fig. 1, whereas in Fig. 2 (ordination based on the Burnaby index) their position is more confused. The relationship between fuzzy sets seems to be independent for the Goodall index, whereas it is linear for the Burnaby index. This means that with the Burnaby in-

dex the more similar a relevé is to one set, the more similar it also is to the other, but at a different level. This fact reflects the relative homogeneity between vegetation

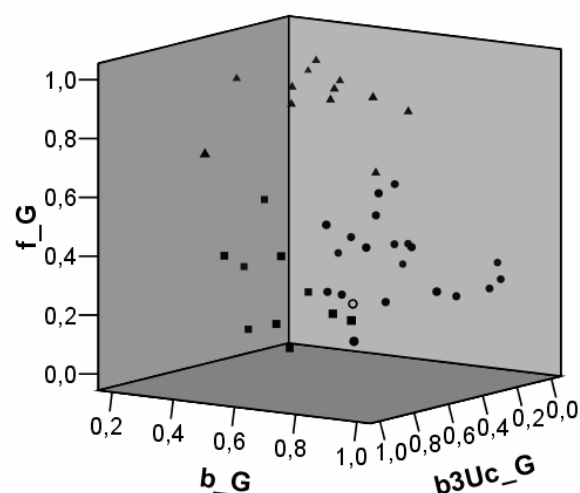


Figure 1. Ordination of the relevés according to the fuzzy sets obtained with the Goodall index (G) of the three vegetation types $b = \textit{Ornithogalo brevistyli-Biforetum testiculatae}$ (■); $b3Uc = \text{grasslands}$ (●) and $f = \textit{Knautio integrifoliae-Anthemidetum triumfetti}$ (▲), the symbol ○ indicates relevés with the same degree of belonging for more than one vegetation type.

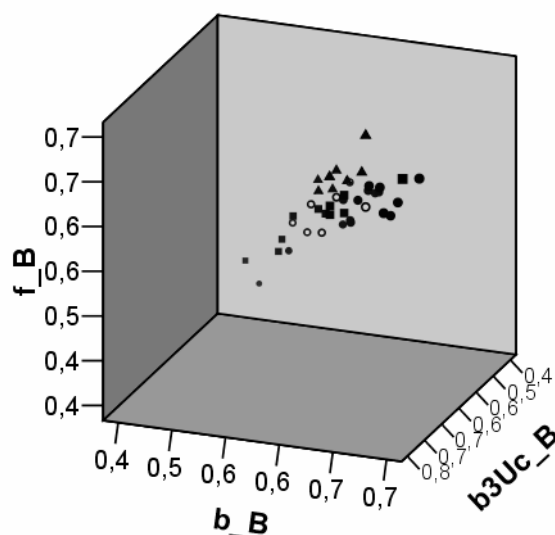


Figure 2. Ordination of the relevés according to the fuzzy sets obtained with the Burnaby index (B) of the three vegetation types $b = \textit{Ornithogalo brevistyli-Biforetum testiculatae}$ (■); $b3Uc = \text{grasslands}$ (●) and $f = \textit{Knautio integrifoliae-Anthemidetum triumfetti}$ (▲), the symbol ○ indicates relevés with the same degree of belonging for more than one vegetation type.

types, as Table 1 suggests very well; in fact the blocks are not sharp and they do not show high concentration values.

Table 2 shows to which vegetation types the similarity functions assign the relevés d, g, h. The relevé d belongs to type b1 according to the cosine index, to type $b3Uc$ according to the Goodall index and COCHIS, and to type e according to the Burnaby index. The relevé g belongs to type f (mainly) and $b3Uc$, while the relevé h is allotted to type e by the cosine index, to $b3Uc$ by the Goodall index, and to f by the other similarity functions.

Discussion

The recognition of different patches of vegetation may suggest the idea that the vegetation is organised in “discrete” plant communities. However the floristic similarity between adjacent vegetation patches suggests that vegetation varies in a continuous manner. The data we have used in the present study are not from relevés of selected vegetation patches, but from cultivated or uncultivated fields distributed widely over the province of Molise. From these data, it is difficult to accept the idea that plant communities are “discrete entities”. However, Ferro et al. (1997) were able to propose two different plant associations and several other vegetation types. The method we have proposed suggests that three vegetation types, rather than seven, suffice. In this classification, some relevés can be assigned with the same degree of belonging to more than one vegetation type. However, one must be prepared to recognize that different similarity functions can give different results, and that often it is difficult to decide to what vegetation type a relevé should be assigned. This is due to the indeterminacy of the vegetation system, which is a consequence of the complexities of vegetation dynamics and of the different weights given by the similarity functions to the “properties” of the species in terms of their frequency and association with other species. Our method defines for each similarity matrix a fuzzy set matrix that shows the degrees of belonging of the relevés to different vegetation types. This is a powerful tool in thinking about a data structure and about the “ecological” meaning of a relevé in terms of its species composition and its environmental and spatial position. With the proposed method, one can test any classification of relevés into vegetation types by calculating the degree of belonging to the corresponding fuzzy sets. When vegetation types have been validated by the S values, one has automatically defined non-random species associations, which may be useful in predicting vegetation changes along gradients or over time. We are confident that the data stored in phytosociological and syntaxonomical data bases as relevés or phytosociological data tables would be

essential to study environmental changes at local and global level in a detail that is useful to understand biodiversity changes.

Conclusions

In conclusion, the method we propose is useful to:

- validate the classification of relevés in phytosociological types suggested by syntaxonomists;
- identify unstable vegetation types and suggest alternatives for a more consistent classification;
- suggest rearrangements of relevés in phytosociological tables to obtain tables that reflect more clearly vegetation “transition” from one type to another along environmental gradients.

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