

# Reliability and effectiveness of Ellenberg's indices in checking flora and vegetation changes induced by climatic variations

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**Abstract:** Two methods are proposed to assess the significance of time-spanned local variations of Ellenberg's indicator values in floristic and phytosociological data sets respectively. Both methods are based on frequencies and averages of the indicator values within and among data sets. Main goal of proposed methods is to determine the threshold above which the observed variations are to be considered significant. In order to relate the observed floristic variations to recent climatic changes, attention was focused on the Ellenberg's indices dealing with the main climatic variables: heliophany, temperature and precipitation. Study-cases from Zannone Island (Pontine Archipelago, Mediterranean region), Inferno Valley (Rome, Mediterranean region) and Braulio Valley (Stelvio National Park, Alpine region) are reported. For Mediterranean data- sets, integration and adjustments to the Ellenberg's indicator values have been adopted.

## INTRODUCTION

Many scientific contributions of the last ten years deal with the responses of living organisms to the recent global warming caused by human activities. As to plants, it is quite difficult to claim that the observed variations are

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*Edited by G.-R. Walther, C.A. Burga and P.J. Edwards*

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strictly related to the global warming, because distribution of species largely depends on non-linear interactions among different environmental variables. Moreover, plant communities often bear feedback mechanisms that buffer slight variations of environmental factors without radical changes in physiognomy and species composition (Wilson & Agnew, 1992).

An attempt to draw indications on the influence of each main environmental factor in determining flora and vegetation changes can be made with the help of Ellenberg's indices. There are large experimental evidence that ecological factors determine both composition and structure of plant communities. On this basis, Ellenberg (1974, 1996; Ellenberg *et al.*, 1992) outlined the synecological requirements of each species belonging to the vascular flora of Central Europe by means of numerical indices referred to 7 main environmental factors. These can be divided in two subgroups of three and four indices respectively. The first three indices are linked to climatic variables: light regime (L), temperatures (T) and continentality of climate (C); the other four deal with edaphic conditions: moisture of soils (M), pH, nutrients availability (N) and salt concentration (S). All indices are arranged in ordinal scales ranging between 1 and 9 (only M ranges between 1 and 12 and S between 0 and 9), where only a nominal correlation with the physical/chemical parameters, measuring the environmental variables to which indices are referred, is given. Another important feature of Ellenberg's indices is that they are not related to the ecological optimum of a given species, but to its synecological optimum, expressing the optimal ecological requirements of a species when in competition with other species, which can vary from region to region.

Ellenberg's indices are defined by the author himself as a useful paradigm to summarise interactions between plants and environment, recognising to each species a role as biological indicator, which has been often neglected or disregarded in recent literature. Ellenberg's indices have been successfully applied to "fingerprint" plant communities and higher syntaxa according to their floristic composition, by means of synoptic representations of their ecological spectra (Van der Maarel 1993, Pignatti *et al.* 1996, Pignatti 1998, 1999, Petersen 2000, Bianco *et al.* 2001, Guarino & Bernardini 2001). Time-spanned variations of such spectra might also be useful in tracking the effects of global changes on local flora and vegetation. Methods for assessing the thresholds above which the observed variations can be considered significant will be the main subject of the present paper.

### **On Ellenberg's indices**

From Central Europe, Ellenberg's model has been extended eastwards to Poland by Zarzycky (1984) and to Hungary by Borhidi (1995). This

extension was not so problematic, thanks to the large number of species in common and to the relatively similar latitudinal distribution. Synecological requirements of a species may change over its range, especially when moving to different latitudes. In order to extend the model to the Italian flora, a data-base has been collected by Pignatti and collaborators since 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 should be published in a relatively short time (Pignatti et al. 1996). From the methodological point of view, the only relevant problem was the necessity to enlarge the scale of T to 12 possible values, since, compared to central Europe, higher temperature may occur in Italy. Aim of the present study was also to check whether the integration proposed for the Italian flora fits the Ellenberg's model in terms of statistical homogeneity.

Some authors (Durwen 1982, Böcker et al. 1983, Möller 1992, Kowarik & Seidling 1989), even if sometimes recognising the usefulness of calculating average values of the Ellenberg's indices for floras or plant communities, believe that such use is incorrect from the mathematical point of view, since Ellenberg's indices are ordinal scales, without dimensional correlation with chemical/physical parameters. It is well-demonstrated (Figure 1) that when the number of data is sufficiently high, Ellenberg's variables fit the normal distribution (Gaussian curve), which is described by the parameters average and variance. In this case, in addition to non-parametric statistics, all statistical tests referring to the normal distribution can be used, since they are based on differences of each sample from the average. Calculating average and variance of data sets is, therefore, allowed as well. When only a small number of data is available, a parametric statistical approach can be tested anyway, because in the case of Ellenberg's scales it is always possible to transform data in their respective ranks, to

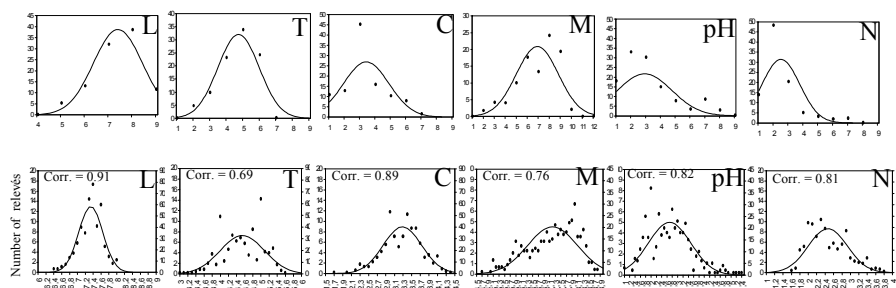


Figure 1. Distribution of Ellenberg's indicator values within a phytosociological table (449 relevés  $\times$  233 species) of Empetro-Ericetum from Wadden Sea Islands (Northern Sea). The first row of diagrams is referred to the distribution of values among the species occurring in the relevés, the second one to the distribution of average indicator values among the relevés.

better approximate the normal distribution and to create the conditions to use a parametric approach.

Moreover, several contributors demonstrated a fairly good correlation between M, pH, N, S indices and measured environmental variables (Degorski 1982, Seidling & Rohner 1993, Möller 1997, Petersen 2000, Schaffers & Sýkora 2000). From the theoretical point of view it is therefore possible, at least for the above-mentioned scales, to find out algorithms that describe linear or non-linear correlation between Ellenberg's scales and chemical concentrations, so to give a dimensional meaning to the Ellenberg's values. Similarly, this holds true also for the others indices (L, T and C).

Carrying out parametric statistical tests and using average indicator values referred to floras and plant communities should be thus considered admissible even from the epistemological viewpoint, as already accepted by many authors and by Ellenberg himself (Pignatti *et al.* 1996). This greatly broadens the usefulness of such indices.

## METHODS

Variations of Ellenberg's indices over the past fifty years were analysed for floras of Inferno Valley (Rome, central Italy), of Zannone (an island belonging to the Pontine Archipelago, central Italy) and for vegetation of Braulio Valley (Stelvio National Park, central Alps) (Figure 2). In the case of Zannone, variations occurred over the first half of the last century have been considered as well. Analyses were performed either on floristic or phytosociological data sets depending on the availability of old data. For the first two localities, belonging to the Mediterranean region, integration and adjustments proposed by Pignatti to the Ellenberg's model were adopted.

In case of floristic data sets (Inferno Valley and Zannone Island), frequencies and average of the indicator values were evaluated for each of the Ellenberg's indices. Such estimates were calculated on total floras, on species in common and on appeared/disappeared species. A similar evaluation was performed for phytosociological data (Braulio Valley), but in this case results have been weighted in the frequency of each species within the phytosociological tables. Cover values of species have been neglected, since the considered time-span was too short to cause remarkable changes in the dominance of plant communities, while appeared or disappeared species were mostly found in few individuals per plot. Indeed, the use of presence/absence values in the calculation of site indicator values is recommended by several authors and by Ellenberg himself (Durwen 1982, Kowarik & Seidling 1989, Ellenberg 1991).

Numerical analyses have been based in each case on parametric statistics and combinatory calculations.

In order to relate the observed floristic variations to recent climatic changes, attention was focused on the Ellenberg's indices dealing with the main climatic variables: heliophany, temperature and precipitation. These are, respectively, the L, T, C and M indices. Owing to the provenance of data, the C index was disregarded, since values of continentality are always very low for Mediterranean species (that dominate the floras of Inferno Valley and of Zannone), while are poorly distinctive for Alpine species. On the other hand, the M index, even if refers to water availability in soil, has been considered because it can be affected temperature and precipitation trend and by variation in total rainfall. Moreover, for the alpine sites, soil moisture can be also influenced by an increased melting rate of glaciers during the vegetative period.

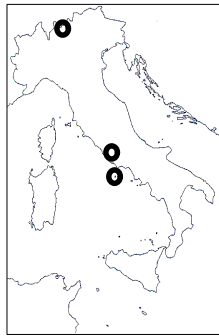


Figure 2. Approx. localisation of data sources (centre of the black circles). From south to north: Zannone Island, Inferno Valley and Braulio Valley.

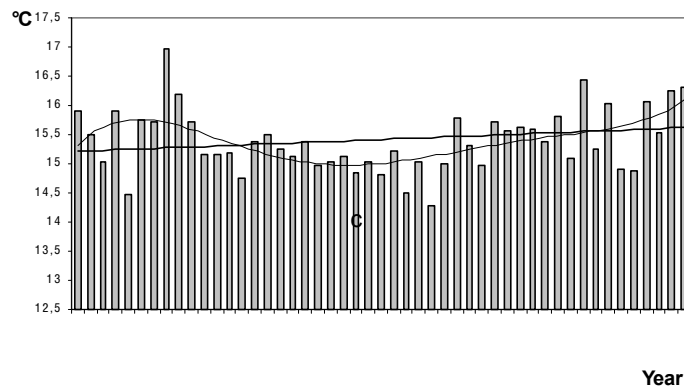


Figure 3. Infrared scanners reveal an average increase of 0.6 °C proceeding from non-urban to urban areas of Rome. The trend of the mean annual temperature (period: 1952-2000) at Monte Mario, representing the south-eastern boundary of the Inferno Valley, is plotted. Besides the regression line, a polynomial curve is presented, expressing the minimum squares within groups of 5 temperature values.

## FLORISTIC DATA

### Data sets

Inferno Valley has an extension of approx. 2.5 km<sup>2</sup> and it is located in Rome, only 2 km far from the centre of the town. Starting from 1930, it has been progressively included in the urban tissue, but it was managed in a

traditional way ("Ager Romanus") until 20 years ago. By comparing the flora of 1954 (Montelucci) to the present one (Bianco & Fanelli, in press) a slight decrease of the total number of species (from 667 to 644) was noted due to the disappearance of 64 species (9.3 % of the 1954 flora) and to the appearance of 41 new ones (6.4 % of the actual flora). Disappeared species belong mostly to the Eurasiatic chorotype, while new ones are mostly adventitious synanthropic and ephemeral Mediterranean species (Table 1).

Observed variations can be related to the increase of human disturbance, to the local/global warming (Figure 3), to the ending of traditional farming and subsequent soil erosion of large areas within the park.

By considering the total floras, the above-mentioned floristic changes led to a slight decrease (-0.13) of the average L value and to an increase of T and M values (0.27 and 0.08, respectively). By comparing the average values of the 64 disappeared species to those of the 41 newly appeared (Figure 4), L and T increased (0.14 and 0.50, respectively) while H decreased (0.56).

Zannone Island has an extension of approx. 1.03 km<sup>2</sup> and it is located along the Tyrrhenian coast, 7 miles off the Circeo headland. It was inhabited by Benedictine monks until the end of the 13<sup>th</sup> century, later only being periodically used as a refuge by Saracen pirates and successively as hunting and wood reserve by local people. At the end of the 19<sup>th</sup> century, few couples of muffs were introduced on the island and around 1950 the population reached 200 individuals. Since 1979, Zannone Island belongs to the Circeo National Park; the muffs-population has been reduced to the actual 30 individuals and fires are extremely rare, the island being permanently patrolled by foresters. Floras of the island were published in 1905 (Bèguinot), 1954 (Anzalone), 1997 (Anzalone et al.). A noteworthy decrease in species richness occurred over the years: from 272 species recorded in 1905, 241 were scored in 1954 and 193 in 1997. The highest turn-over took place in the time gap between the two old floras and the recent one: in addition to the 57 species found only in 1905 and to the 25 ones found only in 1954, a total of 60 species were recorded only in these old floras. Disappeared species are to be ascribed mostly to the Steno-Mediterranean chorotype, while among the new ones a large number are exotic synanthropic species (Table 2). Many of the disappeared species are therophytes, the spreading of which was probably due to the muffs-grazing and to the higher frequency of fires. It appears likely that these mammals caused probably the extinction of the 57 species recorded only in 1905, represented mostly by perennial palatable grasses. Anyway, global warming can not be excluded a priori from the possible causes of such changes.

Observed variations of average L, T, and M values passing between the flora of 1905 and that of 1954 were: -0.02, -0.09 and +0.08, respectively.

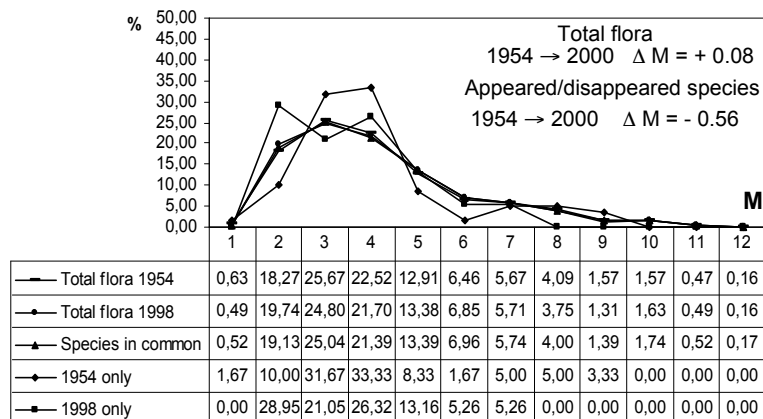
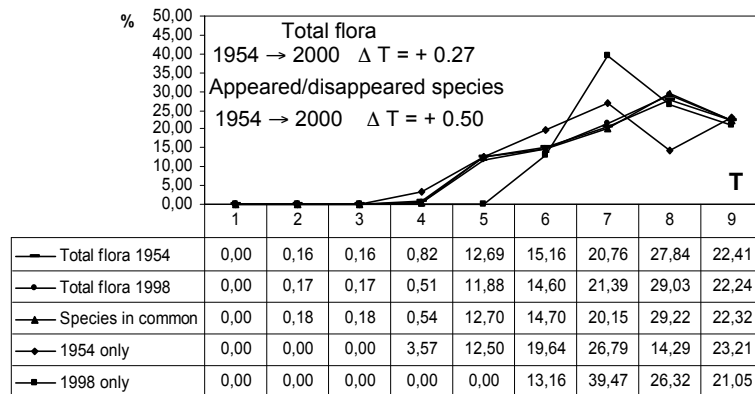
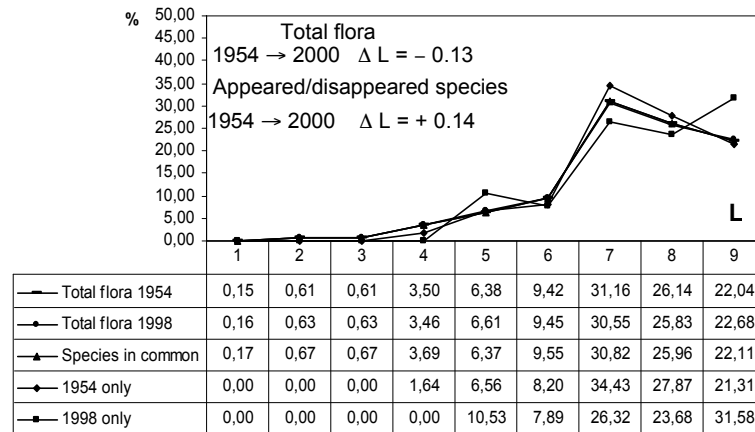


Figure 4. Frequency distribution (percentage) of Ellenberg's indices for light (L), temperature (T) and moisture (M, see next page), for the vascular flora of Inferno Valley. Differences between the average values of the total floras and of the appeared/disappeared species are also given.

observed variations of the same values between the flora of 1954 and that of 1997 were: +0.04, -0.05 and -0.05 respectively. Variations of the average values between the species found exclusively in 1905 and those found exclusively in 1954 or 1997 were the following:  $\Delta L = +0.04$ ;  $\Delta T = -0.32$  and  $\Delta H = +0.11$ . Variations of the average values passing from the species exclusively found in 1905 or 1954 to those exclusively found in 1997 were the following:  $\Delta L = +0.19$ ;  $\Delta T = -0.20$  and  $\Delta H = +0.04$  (Figure 5).

### Data analysis

Can the observed variations of L, T and M be related to variations of environmental factors or should they be considered not significant and therefore negligible?

To answer the question, it was considered that each flora can be divided in subgroups formed by  $n$  species, with  $n$  varying between 2 and the number of species forming the total flora ( $N$ ). The number of possible combinations ( $C$ ) for such groups is given by the following expression:

$$(1) C = \sum_{n=2}^N N!/(N-n)! n!$$

According to the expression (1), when a flora is composed by more than 100 species, the total number of possible combinations can be approximated to  $+\infty$  (Figure 6). Theoretically, it is possible to calculate the average value of a given Ellenberg's index for each of the aforesaid combinations. For each combination it is possible, as well, to calculate the mean absolute deviation  $D_m$  from the average indicator value of the total flora  $\mu$ , according to the following expression:

$$(2) D_m = \sum_{i=1}^n |x_i - \mu| / n$$

where  $x_i$  is the average indicator value of a given combination and  $n$  the total number of possible combinations. Variance of  $D_m$  calculated for each rank of the possible combinations has the theoretical trend represented in Figure 7, with a maximum for combinations including 15 % of the total flora.

Observed variations in Ellenberg's mean values have been considered significant only when both the absolute differences between the mean values referred to the total floras and to the appeared/disappeared species exceeded the highest  $D_m$ , measured within at least 50 subgroups, randomly chosen among the possible combinations including 15 % of the species belonging to each flora.  $D_m$  was preferred to other methods to assess the variability of data sets (such as mean square and standard deviation) because it is directly comparable to the above-mentioned differences.



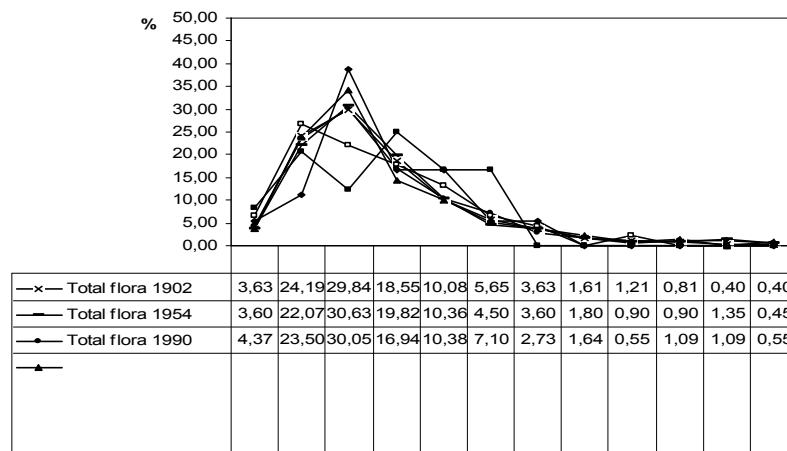


Figure 5. Frequency distribution (percentage) of Ellenberg's indices for light (L), temperature (T) and moisture (M), for the vascular flora of Zannone Island. Differences between the average values of the total floras and of the appeared/disappeared species are also given.

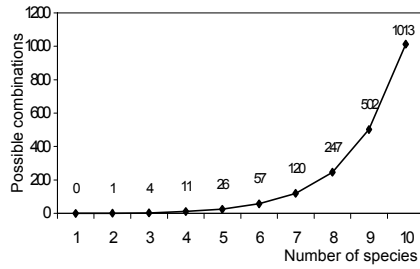


Figure 6. Curve given by the expression (1) for hypothetical floras composed by 1 to 10 species.

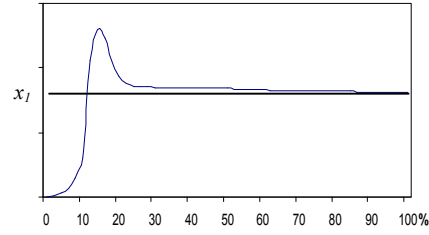


Figure 7. Theoretical curve of the variance of  $D_m$  (see expression 2), calculated on subgroups including from 0 to 100 % of the total flora.  $x_j$  represents the variance of  $D_m$  referred to the total flora.

### Results

In the case of Inferno Valley, the mean absolute deviations of the average L, T, and M values, measured among 50 subgroups of 100 and 128 species (corresponding to the 15 % of the flora of 1954 and of the present one, respectively) gave the following figures:

	$D_m(L)$	$D_m(T)$	$D_m(M)$
Flora 1954	0.201	0.256	0.243
Actual flora	0.187	0.219	0.195

According to the proposed approach, it was concluded that the observed variation of average T indicator values over the last fifty years could be related to the combined effect of local and global thermal increase occurred in the Inferno Valley over the same period (Figure 3). Observed variations of L and M values should be neglected, even if the variation of M (-0.56) occurred within the appeared/disappeared species gives an important indication about a possible evolution towards drier environmental conditions in the next future. These conclusions are resumed by the following expressions:

$$\begin{aligned}
 |\Delta L_{total}| [0.13] \wedge |\Delta L_{app./disapp.}| [0.14] < 0.201 &\Rightarrow \text{negligible} \\
 |\Delta T_{total}| [0.27] \wedge |\Delta T_{app./disapp.}| [0.50] > 0.256 &\Rightarrow \text{meaningful} \\
 |\Delta M_{total}| [0.08] < 0.195 < |\Delta M_{app./disapp.}| [0.56] &\Rightarrow \text{negligible}
 \end{aligned}$$

Variations of Ellenberg’s indices reflected quite well that the more thermophilous character of the new entries, mostly belonging to the Mediterranean chorotype, compared to the disappeared ones, mostly belonging to the Eurasiatic one. The higher xerophily of the new entries can be accounted for in the same way.

In the case of Zannone Island, the mean absolute deviations of the average L, T, and M values, measured among 50 subgroups of 41, 36 and 29

species (corresponding to the 15 % of the flora of 1905, 1954 and 1997, respectively) gave the following results:

	D <sub>m</sub> (L)	D <sub>m</sub> (T)	D <sub>m</sub> (M)
Flora 1905	0.084	0.127	0.083
Flora 1954	0.160	0.119	0.192
Flora 1997	0.133	0.141	0.108

According to the proposed approach, all the observed variation of the average indicators referred to the flora of Zannone Island should be neglected, as shown by the following expressions:

1905 → 1954

$$|\Delta L_{\text{total}}| [0.02] \wedge |\Delta L_{\text{app./disapp.}}| [0.04] < 0.160 \Rightarrow \text{negligible}$$

$$|\Delta T_{\text{total}}| [0.09] < 0.127 < |\Delta T_{\text{app./disapp.}}| [0.32] \Rightarrow \text{negligible}$$

$$|\Delta M_{\text{total}}| [0.08] \wedge |\Delta M_{\text{app./disapp.}}| [0.11] < 0.192 \Rightarrow \text{negligible}$$

1954 → 1997

$$|\Delta L_{\text{total}}| [0.04] < 0.160 < |\Delta L_{\text{app./disapp.}}| [0.19] \Rightarrow \text{negligible}$$

$$|\Delta T_{\text{total}}| [0.05] < 0.141 < |\Delta T_{\text{app./disapp.}}| [0.20] \Rightarrow \text{negligible}$$

$$|\Delta M_{\text{total}}| [0.05] \wedge |\Delta M_{\text{app./disapp.}}| [0.04] < 0.192 \Rightarrow \text{negligible}$$

In the case of Zannone Island, in spite of a total turnover of species higher than 37 % (21 % higher than in Inferno Valley), all the observed variation of the considered Ellenberg's indices are negligible. This supports the hypothesis that floristic variation on the island should be mostly ascribed to the presence of muffs and to changes in fire frequency. The decreasing trend of  $\Delta T$  within the appeared/disappeared species (-0.32 and -0.20, respectively) can be explained if we consider that up to 1939 the southern slope of the island was exploited for charcoal production. It is likely that markedly xerothermophilous species belonging to the class Thero-Brachypodietea (Lygeo-Stipetetea syn. synt.), forming perennial post-fire grasslands widespread on the island in 1905, were heavily grazed by the 200 muffs occurring at that time. Therophytic, less palatable, grasses belonging to the class Tuberarietea guttatae, and characterised by a lower T value (as only their seed survive to the driest period of the year) replaced the overgrazed perennial species. Present vegetation is rapidly evolving toward more complex and stable wooden types, which T values that reflect the relatively mild suboceanic climatic conditions given by the Tyrrhenian Sea. This explanation is well supported by differences in ecological spectra.

## PHYTOSOCIOLOGICAL DATA

### Data sets

Braulio Valley ranges between 2,250 and 3,000 m a.s.l. and has an extension of approx. 9.5 km<sup>2</sup>. It belongs to the Stelvio National Park and witnessed a progressive decrease in traditional land use ("alpeggio") and an increase of tourism during the last fifty years. An exhaustive monograph about flora (including bryophytes and lichens) and vegetation of the valley, including a phytosociological map of the area, was published in 1955 (Giacomini & Pignatti). At present, a working group co-ordinated by Pignatti himself is carrying out a similar research to check possible changes occurred meanwhile. The complete results of such research are supposed to be published within March 2002. According to the preliminary results, no meaningful variation has been recognised within the local flora during the last fifty years. This would agree with the hypothesis, supported by some authors (e.g. Körner 1994, Theurillat 1995), that a slight increase of temperature would not affect significantly the floristic diversity of the Alpine chain.

As to vegetation, 28 different plant communities belonging to 13 phytosociological classes have been investigated up to now by means of the Braun-Blanquet's approach (Braun-Blanquet 1964, Westhoff & Van der Maarel 1976). Small variations have been noted in structure and composition of some phytocoenoses, as well as in the extensions covered by them, as already observed in Braulio Valley by Faifer & Pirola (1995). Among the surveyed associations, *Caricetum curvulae* bears the highest variation in Ellenberg's L, T and M indexes. This is largely due to the enrichment in species of *Nardetea strictae* (and lower syntaxa), that are spreading from the subalpine to the alpine belt (Figure 8). Even if these species are commonly favoured by a high grazing pressure; it is interesting to note that within the *Festucetum halleri*, a plant association widespread in the subalpine belt and supporting the highest grazing pressure in Braulio Valley, such species are clearly decreasing. This observation is in accordance to the progressive reduction of grazers caused by the vanishing traditional way of farming, locally called "alpeggio". This consideration suggests that upwards spreading of *Nardetea*-species might be related to global warming.

Observed variations of average L, T, and M values, weighted in frequency of species within the phytosociological tables, were: -0.37, +0.28 and +0.44 respectively (Figure 9 and Table 3). In the case of Braulio Valley, no integration neither adjustment of Ellenberg's indicator values has been adopted. The few species not occurring in the original list of indicator values have been ignored.

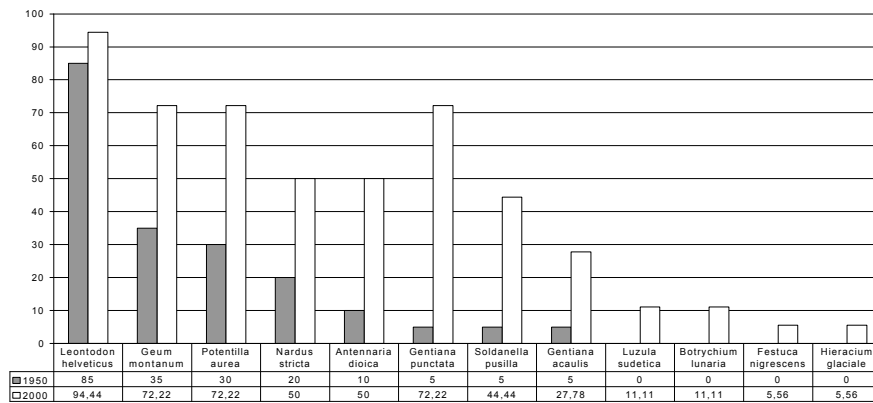


Figure 8. Frequency (percentage) of Nardetea strictae-species within the Caricetum curvulae in Braulio Valley in 1955 and in 2000.

## Data analysis

- 1) Was the number of relevés sufficient to render significant the observed variations?

All relevés were taken along 4 transects approx. 100 m wide. The total estimated area covered by Caricetum curvulae along the transects was 36,000 m<sup>2</sup>. In 1955, 20 relevés of this vegetation have been published (Giacomini & Pignatti 1955a, b). The mean plot size was 68.2 m<sup>2</sup>, corresponding to an investigated area of 1365 m<sup>2</sup> (≅ 3.8 % of the total estimated area along the transects). In 2000, 18 relevés of Caricetum curvulae have been taken, with mean plot size of 62,3 m<sup>2</sup>, corresponding to an investigated area of 1121 m<sup>2</sup> (≅ 3.1 % of the total estimated area along the transects). In order to assess whether the number of relevés was sufficient to include the whole range of variation of Ellenberg's indices within Caricetum curvulae of Braulio Valley, the n possible plots along the transects (528 and 745 respectively) were ascribed to two different classes, A and B, with relative frequencies p and q. The probability P to assign a sample i times to A (and therefore n - i to B) is given by the following binomial distribution:

$$(3) P = [n!/i!(n-i)!] p^i q^{n-i}$$

By means of the expression (3), it is possible to describe, for example, the probability P that 75 % of the 20 samples of 1950 was among those having T values lower than the average (and therefore belonging to the class A) and that 75 % of the 18 samples of 2000 was among those having T values higher than the average (and therefore belonging to the class B),

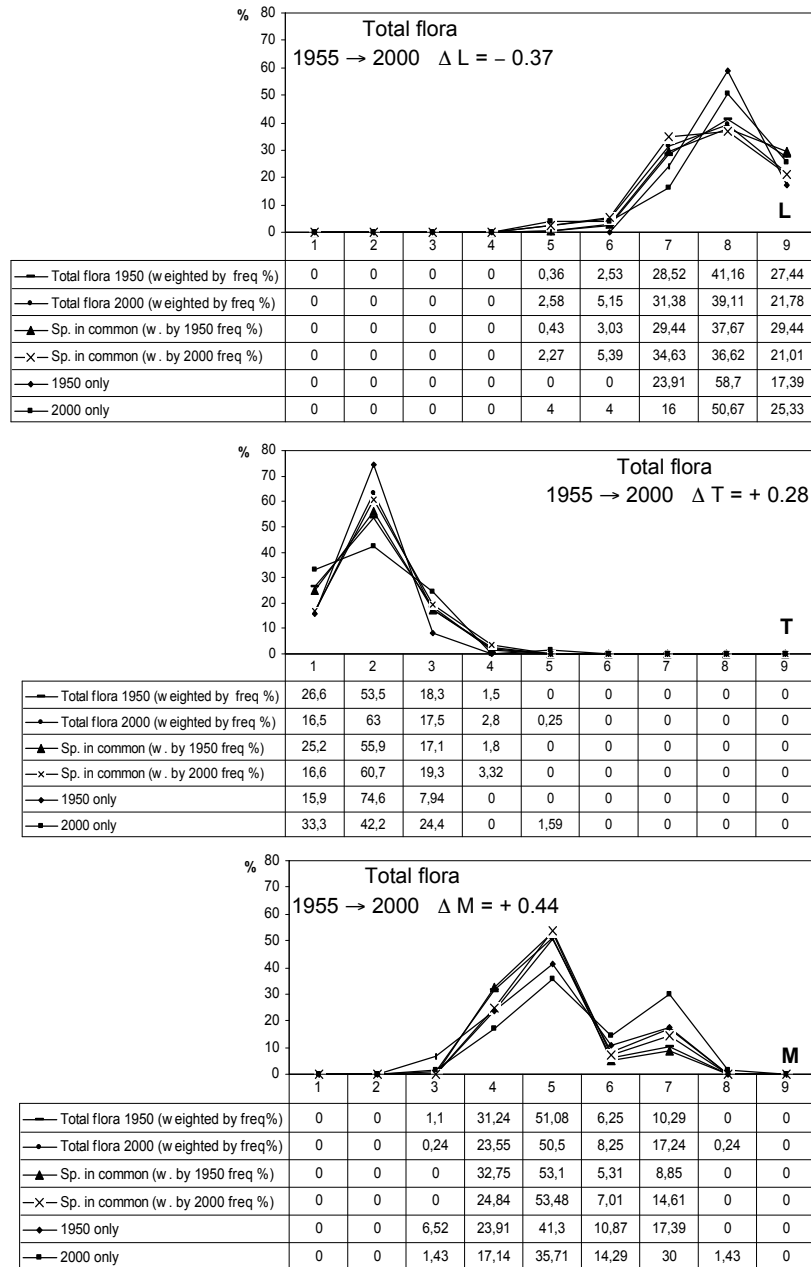


Figure 9. Frequency distribution (percentage) of Ellenberg's indices for light (L), temperature (T) and moisture (M, see next page), referred to the Caricetum curvulae of Braulio Valley. Frequencies have been weighted in the frequency of species within the phytosociological tables. Differences between the average values of the total floras are also given.

according to the variations of  $p$  and  $q$  (Figure 10). By considering the trend of the curves of iso-probability in Figure 10, it is likely that the considered relevés were quite homogeneously distributed along the gradient of possible variations of Ellenberg's indices.

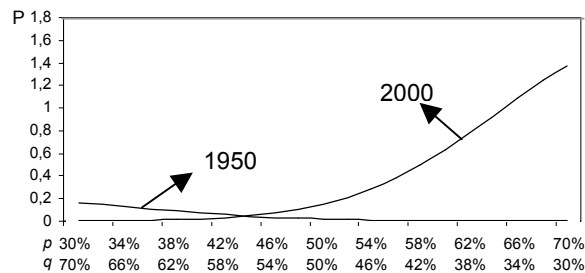


Figure 10. Curve given by the expression (3), describing the probability  $P$  that 75 % of the 20 samples of 1950 was among those having  $T$  values lower than the average (and therefore belonging to the class A), and that 75 % of the 18 samples of 2000 was among those having  $T$  values higher than the average (and therefore belonging to the class B), according to the variations of frequencies of the two classes. Probability is expressed in percentage.

- 2) Can the observed variations of  $L$ ,  $T$  and  $M$  be related to variations of environmental factors or should they be considered not significant and therefore negligible?

The proposed approach used to answer the question will be illustrated taking the  $L$  index as example. The same procedure was followed to assess the significance of the observed variations of  $T$  and  $M$ .

The first step was to calculate the mean  $L$  value for each of the 38 available relevés. It was assumed that indicator values of *Caricetum curvulae* in Braulio Valley were normally distributed among the  $n$  possible plots within the valley. The present approach loses its meaning for other distribution models, as those described by bimodal or sigmoid curves. If the normal distribution of average indicator values is accepted, the distribution of  $L$  values for each sampling area of 1955 can be described by a Gaussian (Figure 11,  $C_1$ ) settled by the average  $L$  of the 20 relevés of 1955 ( $L_1$ ) and by the standard deviation estimated among the  $L$  values of the same set of relevés (Table 4). Analogously, the distribution of  $L$  values for each sampling area of 2000 can be described with a Gaussian (Figure 11,  $C_2$ ) settled by the average  $L$  of the 18 relevés of 2000 ( $L_2$ ) and by the standard deviation estimated among the  $L$  values of the same set of relevés (Table 4).

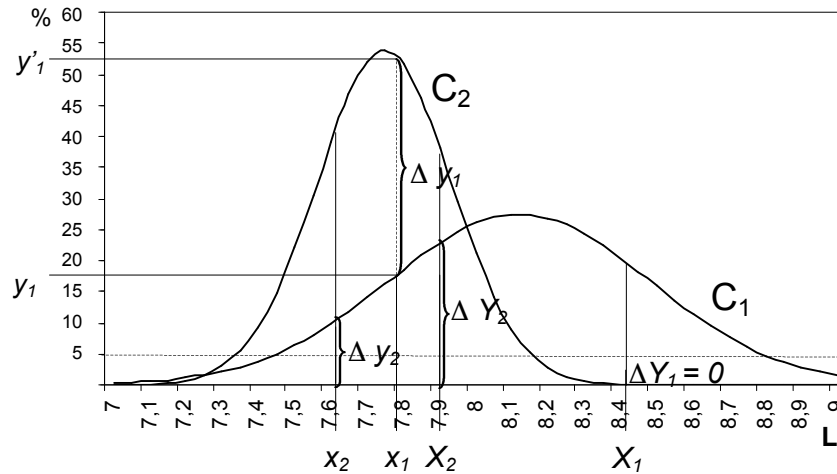


Figure 11. Distribution of L values among the  $n$  possible plots of 1955 ( $C_1$ ) and of 2000 ( $C_2$ ). See text.

With reference to Figure 11, given:

- $x_1$  as the average of L values lower than  $L_1$  among the relevés of 1950;
- $y_1$  as the probability (in %) expressed by  $C_1$  in  $x_1$ ;
- $y'_1$  as the probability expressed by  $C_2$  in  $x_1$ ;
- $\Delta y_1$  as the difference between  $y_1$  and  $y'_1$  (i.e. the difference between the probability expressed by  $C_1$  and the probability expressed by  $C_2$  in  $x_1$ );
- $x_2$  as the average of L values lower than  $L_2$  among the relevés of 2000;
- $\Delta y_2$  as the difference between the probability expressed by  $C_2$  and the probability expressed by  $C_1$  in  $x_2$ ;
- $X_1$  as the average of L values higher than  $L_1$  among the relevés of 1950;
- $\Delta Y_1$  as the difference between the probability expressed by  $C_1$  and the probability expressed by  $C_2$  in  $X_1$ ;
- $X_2$  as the average of L values higher than  $L_1$  among the relevés of 2000;
- $\Delta Y_2$  as the difference between the probability expressed by  $C_2$  and the probability expressed by  $C_1$  in  $X_2$ );

it was assumed that the observed variation of L was significant and not given by chance only when:

$$0 < \Delta y_1 \vee \Delta y_2 \vee \Delta Y_1 \vee \Delta Y_2 < 5 \%$$

i.e. when at least one of the averages of L values above or below  $L_1$  and  $L_2$  were confined in the portion  $C_2$  or  $C_1$  expressing a probability lower than 5%.



## Results

According to the proposed approach, variations observed in the average indicator value for light ( $L_{av}$ ) can be considered significant. The same holds for temperature and moisture indicator values (Figures 12&13). A first observation in Figures 11-13 is the different width of  $C_1$  and  $C_2$ : data of 1955 are more dispersed than those of 2000 (Table 3). Around 1955, pastures of Braulio Valley were intensively grazed by 268 cows and 600 sheep on average (Giacomini & Pignatti 1955b). By excluding rocks, screes and glaciers surrounding the valley, all grazers were concentrated on a surface smaller than 8 km<sup>2</sup>. Nowadays the situation is quite different, as no sheep and less than 100 cows are bred in Braulio Valley during the summer. It is likely that relevés of *Caricetum curvulae* of 1955 were more heterogeneous than those of 2000 because of the more intense grazing pressure. This could also explain the higher  $L_{av}$  of 1955 relevés: disturbance opened new niches in *Caricetum curvulae*, suitable for pioneer species dispersing from contiguous plant communities and characterised by higher L values. Besides, L decrease might be partially related to the decreased albedo caused by the recent retreat of glaciers surrounding the valley. The more intense melting rate of glaciers during the vegetative period (Orombelli et al., 1999) is probably responsible for the higher soil moisture suggested by the increase of  $M_{av}$  indicator value. This conclusion is supported by the similar trend observed in the variation of  $T_{av}$  indicator value, the recent increase of which might be directly related to the global warming and to the shifting upwards of species normally occurring in the subalpine belt (Table 4).

*Figures 12 & 13.* Distribution of T and M values among the n possible plots of 1955 ( $C_1$ ) and of 2000 ( $C_2$ ). See text.

## CONCLUSIONS

Ellenberg's indices seem to be a consistent system to relate observed variations in flora and vegetation of a given site to variations of

environmental factors, and to compare data from different sites. Up to now, the attention of scientists was mostly concentrated in testing the consistency of the system for M, pH, N and S indicator values, by referring to instrumental measurements on a topographic sequence. In the present study, the consistency of Ellenberg's indices was tested against the effects of climate change on a chronological sequence for the first time. Since no local instrumental measurements were available to support the observed variations of indicator values, an attempt to validate the hypotheses per analogy, by means of statistical inferences, was carried out. On this basis, a tentative approach to assess the significance-thresholds of the observed variations has been proposed. A similar approach, with different calibration, might be also used for indices similar to the Ellenberg's ones but adopting scales of different amplitude, such as those proposed by Landolt (1977) for the Swiss flora.

The proposed approach can be used even in case of a hypothetical incongruity of ecological preferences of a given species from Central to Southern Europe, since in time-spanned observations, variations are referred to the same locality. Therefore, the ordinal position of the indicator value of a given species is irrelevant, meaning only that the species has the same indicator value in different data-sets. Anyway, integration and adjustments proposed by Pignatti to adapt the Ellenberg's model to the Italian flora resulted quite homogeneous in the latter, in terms of amplitude and distribution of variance.

Usefulness of Ellenberg's indices in environmental analyses mostly derives from the simplicity of the model. This model does not consider interactions among environmental variables and operates in the frame of a reductionistic paradigm. Any calibration or integration including such interactions would unavoidably complicate the model and render it to less general application, as already noted by Ter Braak & Gremmen (1987). Ellenberg's indices achieve their maximum significance in synthetic-comparative studies on large temporal and/or spatial scales, so any complication of the model should be avoided. Averaging indicator values can be recommended as the simplest way to present such values in a synthetic way, worthy to be statistically compared on macroscales. By studying plants at the small scale, one can observe many differences even among contiguous populations of the same species. Ellenberg's indices certainly are not useful to check such variations, but "duc in altum" It is impossible to appreciate paintings keeping the nose upon the canvas!

"Generalisations about vegetation are urgently required to solve pressing problems created by modern land use, climate change and pollution. If one approaches vegetation with the tools of the watchmaker, there is no limit to the dissection which can be achieved. But if, like Heinz Ellenberg, one raises

one's eyes to the broader canvas, the generalisations are there to be discovered" (after Thompson et al., 1993).

## ACKNOWLEDGEMENTS

We are grateful to Dr. Annette Menzel and to Prof. Conradin A. Burga, Peter J. Edwards, Frank Klötzli, Christian Körner, Hans Möller, Michael Richter, and Reto J. Strasser for their helpful comments and suggestions.

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