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# VEGETATION–ENVIRONMENT RELATIONSHIPS IN THE ULTRAMAFIC AREA OF MONTE FERRATO, ITALY

Alessandro Chiarucci,* Michele Riccucci, Carlo Celesti, and Vincenzo De Dominicis
*Dipartimento di Biologia Ambientale, Università di Siena via P.A. Mattioli 4, Siena 53100, Italy*

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## ABSTRACT

Relationships between some environmental features and species composition and abundance of grassland and dwarf shrub vegetation were investigated on Monte Ferrato, one of the best known ultramafic (serpentine) sites of Italy. The main aim was to test the importance of the available fraction of soil metals in causing the typical infertility of ultramafic soils. The physical and chemical features of soil were determined for each plot in which species composition and cover were recorded. The plots were classified by cluster analysis and ANOVA was applied to compare the environmental variables of groups of plots. Canonical Correspondence Analysis (CCA) was used to detect the principle factors related to the gradient of species composition within the plant communities. It was found that the grassland and dwarf vegetation of Monte Ferrato is not negatively influenced by soil content of nickel and other metals. Pine canopy cover, which provides additional nutrient input and protects against erosion, was found to be important for evolution of the garigues into grasslands. The evolution of grassland turf induced the retention of higher levels of exchangeable cations, including potentially toxic metals, in the evolved soil.

## INTRODUCTION

Because of their physical–chemical features, ultramafic (traditionally referred as "serpentine") areas usually have very distinctive vegetation with respect to adjacent areas. Ultramafic soils are frequently shallow, permeable, and deficient in nutrients, with a high Mg/Ca ratio and relatively high concentrations of potentially toxic metals, such as Ni, Cr, and Co (Proctor and Woodell, 1975; Brooks, 1987; Baker et al., 1992; Roberts and Proctor, 1992). Several ultramafic outcrops can be found in Tuscany, central Italy, and their typical flora and vegetation have been studied (Vergnano Gambi, 1992). The most characteristic vegetation type is a steppe-garigue, described as *Armerio-Alyssetum bertolonii*, which is characterized by plants endemic to these environments or showing typical serpentinomorphoses and by low ground cover and species richness (Arrigoni et al., 1983; Chiarucci et al., 1995). Several authors explained the typical infertility of the ultramafic soils of Tuscany on the basis of the elevated metal, especially nickel, content of the soil (Sasse, 1979; Arrigoni et al., 1983; Vergnano Gambi, 1992). Recently, Chiarucci and De Dominicis (1995) and Chiarucci (1996) suggested that the role of metals should be reconsidered with respect to hydrological and nutritional stresses.

The aim of the present paper is to investigate the relationships between the different plant communities and the main soil features, with special reference to the influence of soil metal content on the vegetation.

## MATERIALS AND METHODS

### *SITE DESCRIPTION*

Monte Ferrato (lat 43°55′N, long 11°05′W) is a hilly complex consisting of three hills, located near the town of Prato and constituted by serpentinites and, to a lesser extent, gabbros and basalts (Vergano Gambi, 1992). The elevation of this area is 100 – 440 m a.s.l. Climate is sub-Mediterranean, with an average annual rainfall of

*Author to whom correspondence should be addressed. E-mail: chiarucci@unisi.it

953 mm and annual temperature of 14.3 °C. July is the driest month, with an average rainfall of 32 mm, and October the wettest, with 132 mm. July is the hottest month, with an average temperature of 24.6 °C, and January the coldest, with 4.7 °C (data from the climatic station of Prato).

Monte Ferrato is one of the most important and well-studied ultramafic sites in Italy. In 1874, during the International Congress of Botany in Florence, an excursion was made to Monte Ferrato (Atti Congresso Internazionale Botanico, 1876). Fiori (1914) and Messeri (1936) have studied its flora and vegetation. In 1934, the Seventh International Phytogeographical Excursion was on Monte Ferrato (Negri et al., 1934). In 1974 there were descriptive papers on bryophytes (Cortini Pedrotti, 1974), flora (Arrigoni, 1974), and vegetation (Corti, 1974) of this site. A third international excursion was made to Monte Ferrato during an Organization for the Phyto-Taxonomic Investigation of the Mediterranean Area (OPTIMA) meeting in Florence (Arrigoni et al., 1979). During this meeting a motion for the safeguarding of this area was passed (Webbia 34: 24–25, 1979). Finally, a phytosociological description of the garigues and grasslands was provided by Arrigoni et al. (1983) and a synthetic study of the garigues of Tuscan ultramafic soils was published by Chiarucci et al. (1995). A revision of the vascular flora is currently underway (C. Ricceri, pers. commun.)

### *VEGETATION SAMPLING*

The plant communities investigated in the present study were restricted to the grassland and dwarf shrub communities most characteristic of the ultramafic soils of Tuscany. Woody coenoses are, with the exception of artificial pine plantations, very rare and often limited to sites of geological contacts (Messeri, 1936; Pichi Sermolli, 1948).

The vascular plant communities were recorded by means of fifty $2 \times 2$ m plots. The percentage cover of each species within a plot was carefully estimated. Sample quadrats were placed at random in uniform areas where the vegetation cover was estimated as homogeneous and away from marked discontinuities. The average canopy cover of pines within a radius of 10 m from the plot and number of pine seedlings in each plot were also recorded. Nomenclature is in accordance with Arrigoni (1974) and Chiarucci et al. (1995) for serpentinophytes and with Pignatti (1982) for other species.

### *SOILS AND ENVIRONMENTAL VARIABLES*

Five regularly spaced soil subsamples were collected, at a depth of about 10 cm in each plot. The composite soil samples were air dried and passed through a 2-mm sieve. A 1:2.5 soil–water suspension was used for a potentiometric measure of pH. Percentage loss-on-ignition (LOI) was measured after heating soil subsamples overnight at 400 °C. Exchangeable cations were extracted by shaking 2-g subsamples of soil, sieved at 125 µm, for 24 h with 20 ml of 1 M ammonium acetate (adjusted to pH 7) and filtering (Whatman No. 42 paper). Element concentrations were determined by inductively coupled plasma emission spectrometry (Perkin Elmer, Plasma 400).

The following features were also recorded for each plot: aspect, slope (°), total ground cover of vegetation (%), rockiness (%), and stoniness (%). The index of normalized insolation (Bartorelli, 1967) was also calculated for each plot. This index expresses the hours per year equivalent of sunshine normal to a site as a measure of the radiation the site actually receives, given its aspect, slope, and latitude.

### *STATISTICAL ANALYSIS*

The total cover of each species was analyzed. The plots were classified by a homogeneity-optimizing procedure: cluster analysis, using the minimization of sums of squares in new clusters (Anderberg, 1973; Podani, 1994) as the agglomeration algorithm, was applied to a distance matrix constructed on the basis of chord distance, after logarithmic transformation of cover data. Cluster analysis was performed with the program package SYN-TAX 5.0 (Podani, 1993). Soil and environmental data of the groups of plots emerging from cluster analysis were subjected to ANOVA; statistical differences between groups were tested by the Student Newman Keuls test (SNK test) at $p < 0.05$. To satisfy the normality assumptions of statistical analysis, the variables rockiness, stoniness, LOI, and exchangeable cations were logarithmically transformed.

To detect gradients in species composition and species–environment relationships, a canonical correspondence analysis (CCA) ordination was performed using the program package CANOCO 3.11 (ter Braak, 1988). Cover data were log-transformed and only species with a frequency higher than 2 were included. In CCA, rare species were downweighted, and to test the significance of the eigenvalue corresponding to the first CCA canonical axis, a Monte Carlo permutation test was applied (ter Braak, 1988).

## RESULTS

### *VEGETATION*

The main clusters (Fig. 1) divided the plots dominated by *Brachypodium rupestre* (Group 4) from the others. Then the steppe-garigues (Group 1) were sepa-

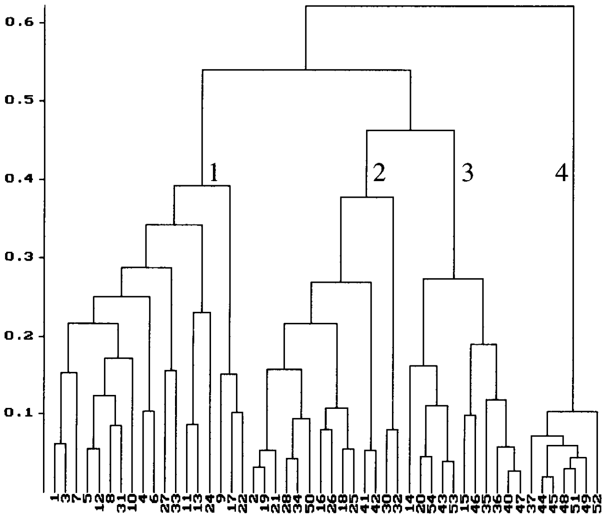


Fig. 1. Dendrogram showing the classification of the 50 vegetation plots.

rated from the xeric grasslands dominated by *Bromus erectus* (Group 2) or *Danthonia alpina* (Group 3). The steppe-garigues of Group 1 belong to the *Armerio-Alyssetum bertoloni* subass. *typicum*, originally described for Monte Ferrato (Arrigoni et al., 1983), common in all the ultramafic areas of inland Tuscany (Chiarucci et al., 1995), and are characterized by several species endemic to Tuscan serpentine soils (Table 1).

The grasslands dominated by *Bromus erectus* (Group 2) belong to the alliance *Bromion erecti* and follow the garigues in the vegetation dynamics of Monte Ferrato ultramafic soils (Arrigoni et al., 1983). They are characterized by an abundance of graminoid species, e.g., *B. erectus* and *Festuca robustifolia*, but also by a high frequency of garigue species, e.g., *Alyssum bertolonii*, *Centaurea aplolepa* ssp. *carueliana*, *Thymus acicularis* var. *ophioliticus*, and chamaephytes, e.g., *Cistus salvifolius*, *Helichrysum italicum*. The grasslands of Group 3 were dominated by *Danthonia alpina*. *B. erectus* was also abundant and *F. robustifolia* was even more abundant than in Group 2. In their study on garigue and grassland vegetation of Monte Ferrato, Arrigoni et al. (1983) did not record plant communities dominated by *D. alpina* and did not find this species. Messeri (1936) quoted its presence in the plant collection of the Florentine botanist Levier. *Danthonia alpina* is, presently, very common on Monte Ferrato and dominates this vegetation type.

The grassland communities of Group 4 were dominated by *Brachypodium rupestre*. Messeri (1936) reported that these grasslands were rare on Monte Ferrato and did not grow under pine cover as did "xeric *Festuca* grasslands" (which probably correspond to our *Bromus* grasslands, in which *F. inops* and *F. robustifolia* are abundant). Arrigoni et al. (1983) reported *B. rupestre* grasslands under a constant but low pine cover: 1–2 of the Braun-Blanquet (1932) scale. *B. rupestre* may have spread in recent times owing to natural or anthropogenic causes.

### *SPECIES DIVERSITY AND GROUND COVER*

A total of 79 vascular plants were found in the 50 plots; average species number per plot was 16.6. The steppe-garigues, characterized by low ground cover and a relatively low species richness (Pichi Sermolli, 1948; Chiarucci et al., 1995), with respect to similar plant communities on other soils, showed the highest species richness in the present survey (Table 2). Species richness of Groups 2 and 3, which was similar to that of Group 1, was statistically higher than in the *Brachypodium rupestre* grasslands (Group 4). Ground cover was significantly higher in Group 4 than Group 1; the cover of *B. erectus* grasslands (Group 2) was statistically lower than that of *Brachypodium rupestre* grasslands (Group 4), whereas that of *Danthonia alpina* grasslands (Group 3) was intermediate (Table 2).

Pine seedlings established preferentially in the xeric grasslands, especially those dominated by *Danthonia alpina*. They did not colonize *Brachypodium rupestre* grasslands (Table 3), probably being prevented by the dense turf.

### *SOIL AND PHYSICAL ENVIRONMENT*

The main soil features are reported in Table 4. Organic matter content and availability of exchangeable cations increased from garigues to xeric grassland and *Brachypodium rupestre* grassland vegetation types, whereas pH, rockiness, and stoniness decreased. Chromium, cobalt, and copper, present in high total concentrations in ultramafic soils (Brooks, 1987), were at the lower limits of detection (0.5 $\mu g\ g^{-1}$) in the soil extracts and are not reported; however, an increasing pattern similar to the other exchangeable cations was observed. The index of normalized insolation did not show any significant differences between the four groups. The *Brachypodium rupestre* grasslands differed in that they were located on steeper slopes and under denser pine cover. The xeric grasslands had intermediate pine cover, whereas garigues were found in places with the lowest pine cover. The magnesium:calcium ratio, which has been considered an important limiting factor for some serpentine flora (Brooks, 1987; Proctor and Nagy, 1992), was significantly higher under the garrigue communities.

The greater availability of metals in the soil under the more mature and structured grassland vegetation types

Table 1
Species frequency (F) according to a five-point scale (I, <20%; II, 20–40%; III, 40–60%; IV, 60–80%, V, 80–100%) and mean cover (C) in the four groups of plots obtained by cluster analysis. +, mean cover less than 0.01

| Group of plots | 1 | | 2 | | 3 | | 4 | |
|---|---|---|---|---|---|---|---|---|
| | F | C | F | C | F | C | F | C |
| *Poa bulbosa* | II | 0.19 | | | | | | |
| *Micropus erectus* | II | 0.01 | | | | | | |
| *Tuberaria guttata* | I | 0.01 | | | | | | |
| *Cheilanthes marante* | I | 0.03 | | | | | | |
| *Jasione montana* | I | + | | | | | | |
| *Cynodon dactylon* | I | 0.03 | | | | | | |
| *Cerastium ligusticum* | V | 0.13 | II | 0.03 | | | | |
| *Sedum rupestre* | IV | 0.78 | I | 0.02 | | | | |
| *Hernaria glabra* | IV | 0.23 | I | + | | | | |
| *Anthyllis vulneraria* ssp. *rubriflora* | III | 0.17 | I | + | | | | |
| *Aira elegans* | III | 0.02 | II | 0.03 | | | | |
| *Leopoldia comosa* | II | 0.01 | I | + | | | | |
| *Hypochoeris achyrophorus* | II | 0.04 | I | 0.01 | | | | |
| *Dianthus sylvestris* ssp. *longicaulis* | II | 0.07 | I | 0.01 | | | | |
| *Filago germanica* | II | 0.06 | II | 0.05 | | | | |
| *Vulpia ciliata* | I | 0.03 | I | + | | | | |
| *Echium vulgare* | I | + | I | 0.01 | | | | |
| *Centaurum pulchellum* | I | 0.02 | I | 0.01 | | | | |
| *Asterolinun linum-stellatum* | I | + | I | + | | | | |
| *Artemisia alba* | I | 0.72 | I | 3.57 | | | | |
| *Briza* sp. | I | 0.01 | I | 0.01 | | | | |
| *Stipa etrusca* | I | 0.17 | II | 1.30 | | | | |
| *Euphorbia exigua* | I | + | II | 0.08 | | | | |
| *Armeria denticulata* | IV | 0.58 | | | I | 0.02 | | |
| *Minuartia laricifolia* ssp. *ophiolitica* | I | 0.06 | | | I | + | | |
| *Brachypodium dystachyum* | I | 0.16 | | | I | 0.01 | | |
| *Linum tenuifolium* | I | 0.01 | | | I | + | | |
| *Alyssum bertolonii* | IV | 0.20 | II | 0.08 | I | 0.09 | | |
| *Potentilla hirta* | IV | 1.12 | III | 0.32 | II | 0.16 | | |
| *Timus acicularis* var. *ophioliticus* | V | 3.81 | V | 1.82 | III | 0.80 | | |
| *Festuca inops* | V | 7.00 | V | 3.50 | III | 0.75 | | |
| *Linum trigynum* | V | 0.28 | V | 0.19 | IV | 0.05 | | |
| *Centaurea aplolepa* ssp. *carueliana* | IV | 1.29 | IV | 1.59 | III | 0.55 | | |
| *Hieracium pilosella* | III | 0.15 | IV | 0.13 | III | 0.03 | | |
| *Cuscuta epithymum* | I | + | II | 0.04 | I | + | | |
| *Hieracium piloselloides* | III | 0.13 | IV | 0.36 | IV | 0.19 | | |
| *Trinia glauca* | II | 0.05 | I | 0.08 | IV | 0.73 | | |
| *Sonchus asper* | | | I | + | | | | |
| *Koeleria splendens* | | | I | 0.13 | | | | |
| *Erica scoparia* | | | I | 0.04 | | | | |
| *Silene italica* | | | | | I | 0.04 | | |
| *Rubus ulmifolius* | | | | | I | 0.01 | | |
| *Pseudolysimachion barrelieri* ssp. *nitens* | | | | | I | 0.01 | | |
| *Poligala flavescens* | | | | | I | 0.04 | | |
| *Plantago lanceolata* | | | | | I | 0.01 | | |
| *Lactuca serriola* | | | | | I | + | | |
| *Genista pilosa* | | | | | I | 0.23 | | |
| *Aster linosyris* | | | | | II | 0.33 | | |
| *Asperula cynanchica* | | | | | I | + | | |
| *Agrostis tenuis* | | | | | I | + | | |
| *Allium sphaerocephalon* | IV | 0.03 | IV | 0.03 | III | 0.01 | I | + |

Table 1 *continued*

| Group of plots | 1 F | 1 C | 2 F | 2 C | 3 F | 3 C | 4 F | 4 C |
|---|---|---|---|---|---|---|---|---|
| *Reicardia picroides* | IV | 0.22 | IV | 0.25 | II | 0.03 | I | 0.04 |
| *Bromus erectus* | III | 0.69 | V | 19.30 | V | 8.18 | I | 0.21 |
| *Helichrysum italicum* | II | 0.42 | IV | 1.01 | III | 0.93 | I | 0.04 |
| *Festuca robustifolia* | IV | 7.72 | IV | 8.25 | V | 22.7 | III | 0.81 |
| *Centaurea rupestris* | II | 0.33 | III | 1.48 | IV | 2.35 | III | 1.06 |
| *Genista januensis* | II | 0.59 | III | 0.34 | V | 0.45 | III | 0.07 |
| *Cistus salvifolius* | II | 0.31 | IV | 1.90 | I | 0.39 | III | 0.29 |
| *Sanguisorba minor* ssp. *muricata* | I | 0.17 | II | 0.20 | III | 0.27 | I | 0.01 |
| *Galium corrudifolium* | II | 0.14 | IV | 1.14 | V | 0.74 | V | 0.53 |
| *Dantonia alpina* | I | + | I | 0.46 | V | 40.1 | II | 0.86 |
| *Vincetoxicum hirundinaria* | I | + | II | 0.17 | IV | 0.09 | III | 0.24 |
| *Carlina corymbosa* | I | 0.01 | III | 0.32 | III | 0.07 | III | 0.20 |
| *Silene paradoxa* | I | 0.01 | I | 0.01 | | | II | 0.09 |
| *Stachys recta* ssp. *serpentinii* | I | 0.01 | I | 0.02 | | | I | 0.01 |
| *Anthericum liliago* | I | 0.01 | | | | | I | 0.01 |
| *Euphorbia nicaensis* var. *prostrata* | I | 0.01 | | | III | 0.20 | II | 0.07 |
| *Brachipodium rupestre* | I | 0.17 | | | I | 0.05 | V | 81.40 |
| *Tanacetum corymbosum* | | | I | 0.06 | | | III | 0.30 |
| *Inula viscosa* | | | I | + | I | 0.01 | I | 0.14 |
| *Picris hieracioides* | | | I | + | I | 0.08 | I | + |
| *Scorzonera austriaca* | | | I | 0.03 | III | 0.07 | I | 0.09 |
| *Hippocrepis multisiliquosa* | | | I | + | III | 0.09 | II | 0.08 |
| *Lotus corniculatus* | | | | | II | 0.10 | II | 0.06 |
| *Knautia arvensis* | | | | | I | 0.02 | III | 0.19 |
| *Dorycnium hirsutum* | | | | | I | 0.09 | I | 0.06 |
| *Carex humilis* | | | | | II | 1.03 | III | 0.79 |
| *Filipendula vulgaris* | | | | | | | I | 0.57 |

Table 2

Species richness and ground cover (mean ± S.E.) in the four groups of plots obtained by cluster analysis. Different letters indicate statistically significant differences between groups

| Group of plots | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| n | 18 | 14 | 11 | 7 |
| Species richness | 18.8 ± 0.9 a | 17.0 ± 0.8 a | 17.3 ± 1.8 a | 9.4 ± 1.2 b |
| Ground cover | 31.7 ± 4.4 a | 50.9 ± 6.6 b | 61.8 ± 7.4 bc | 76.4 ± 8.5 c |

Table 3

Number of pine seedlings (mean ± S.E. calculated from logarithmically transformed data) in the four groups of plots obtained by cluster analysis. Different letters indicate statistically significant differences between groups

| Group of plots | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| n | 18 | 14 | 11 | 7 |
| *Pinus* seedlings | 2.8 ab | 5.7 a | 8.3 a | 0.1 b |
| | (2.0–4.0) | (4.1–7.8) | (5.2–12.8) | (0.4–1.6) |

Table 4
Soil and physical environment variables (mean ± S.E.) in the four groups of plots obtained by cluster analysis. Different letters indicate statistically significant differences between groups

| Group of plots | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| n | 18 | 14 | 11 | 7 |
| Normalized insolation | 2030 ± 57 | 2242 ± 50 | 2085 ± 84 | 2240 ± 193 |
| Slope | 13.6 ± 1.2 a | 13.3 ± 1.3 a | 15.5 ± 2.0 a | 25.4 ± 2.4 b |
| Rockiness | 6.6a | 2.8b | 1.4b | 1.1b |
| | (5.5–7.8) | (2.0 –3.8) | (0.9–2.1) | (0.5–2.2) |
| Stoniness | 53.1a | 16.1b | 1.5c | 0.4c |
| | (47.7–59.0) | (11.6–22.1) | (1.0 –2.2) | (0.2–0.7) |
| LOI | 10.8a | 13.5b | 18.8c | 23.7c |
| | (10.1–11.5) | (12.6–14.3) | (17.6–19.9) | (22.5–24.9) |
| pH | 6.93 ± 0.04 a | 6.68 ± 0.05 b | 6.55 ± 0.08 b | 6.18 ± 0.09 c |
| Pine cover | 9.2 ± 2.0 a | 21.6 ± 3.1 b | 24.5 ± 2.7 b | 42.9 ± 4.7 c |
| Mg/Ca | 3.14 ± 0.35 | 2.29 ± 0.15 | 2.69 ± 0.21 | 2.17 ± 2.01 |
| Ca | 752 a | 1077 b | 1172 b | 1318 b |
| | (706–801) | (1031–1126) | (1104–1244) | (1232–1410) |
| Mg | 2165 a | 2408 ab | 3048 b | 2814 b |
| | (2037–2301) | (2259–2566) | (2832–3279) | (2631–3009) |
| K | 65.4 a | 96.6 b | 94.2 b | 95.0 b |
| | (61.2–69.8) | (89.3–104.4) | (85.4–103 .8) | (87.3–103.4) |
| Na | 33.4 a | 37.7 a | 41.1 a | 56.2 b |
| | (31.0–36.0) | (36.2–39.3) | (38.4–44.0) | (50.6–62.4) |
| Mn | 6.1 a | 19.6 b | 21.9 b | 42.1 c |
| | (5.4–6.9) | (16.6–23.9) | (17.3–27.6) | (29.4–60.3) |
| Fe | 0.4 a | 0.5 a | 0.6 a | 1.3 b |
| | (0.3–0.5) | (0.4–0.6) | (0.5–0.6) | (1.0–1.6) |
| Zn | 0.8 a | 0.9 a | 1.0 a | 1.9 b |
| | (0.7 –0.9) | (0.8–1.1) | (0.9–1.1) | (1.5 –2.4) |
| Ni | 7.3 a | 15.5 b | 23.1 c | 25.6 c |
| | (6.7 –10.0) | (13.7–19.5) | (20.2–28.3) | (22.6–31.0) |

Normalized insolation is expressed in hours per year equivalent of sunshine normal to a site; slope in degrees; rockiness, stoniness, loss on ignition (LOI), and pine cover in percentage; and the concentration of exchangeable cations in $\mu g\ g^{-1}$. Values in parentheses represent S.E. range after log-transformed data.

may be due to the lower pH. Robinson et al. (1996), for example, found that metal solubility in New Zealand serpentines increased exponentially with decreasing pH of the extracting solution.

*GRADIENT ANALYSES*

The CCA ordination of plots and environmental variables is shown in Fig. 2. The eigenvalues of axes 1 and 2 are 0.526 and 0.268, respectively. The cumulative percentage of variance explained by the first two axes accounts for 27.4% (18.2% and 9.2%) of species data and 56.5% (37.4% and 19.1%) of species–environment relations; A Monte Carlo permutation test showed that the first axis significantly contributed to the explained variance ($p < 0.01$). A clear trend from the *Armerio-Alyssetum bertolonii* garigues to the *Bromus erectus* grasslands, the *Danthonia alpina* grasslands, and then to the *Brachypodium rupestre* grasslands was observed from the negative to the positive side of the first axis. This axis was positively correlated with slope, pine cover, organic matter (LOI), nickel, manganese, calcium, sodium, and negatively with stoniness and pH (Table 5).

As to the behavior of the different species (Fig. 3), *Herniaria glabra*, *Cerastium ligusticum*, *Sedum rupestre*, *Potentilla hirta*, *Linum trigynum*, *Festuca inops*, and *Timus acicularis* var. *ophioliticus* (typical of the garigues and the less evolved grassland stages) are related to high rockiness, stoniness, pH, and Mg/Ca ratio. The most typical grassland species, such as *Bromus erectus*, *Danthonia aplina*, and *Carex humilis*, tend to locate in sites with the highest content of soil exchangeable cations and with elevated organic matter and pine canopy cover. *Brachypodium rupestre* is related to the highest slopes, also in sites with elevated pine canopy cover.

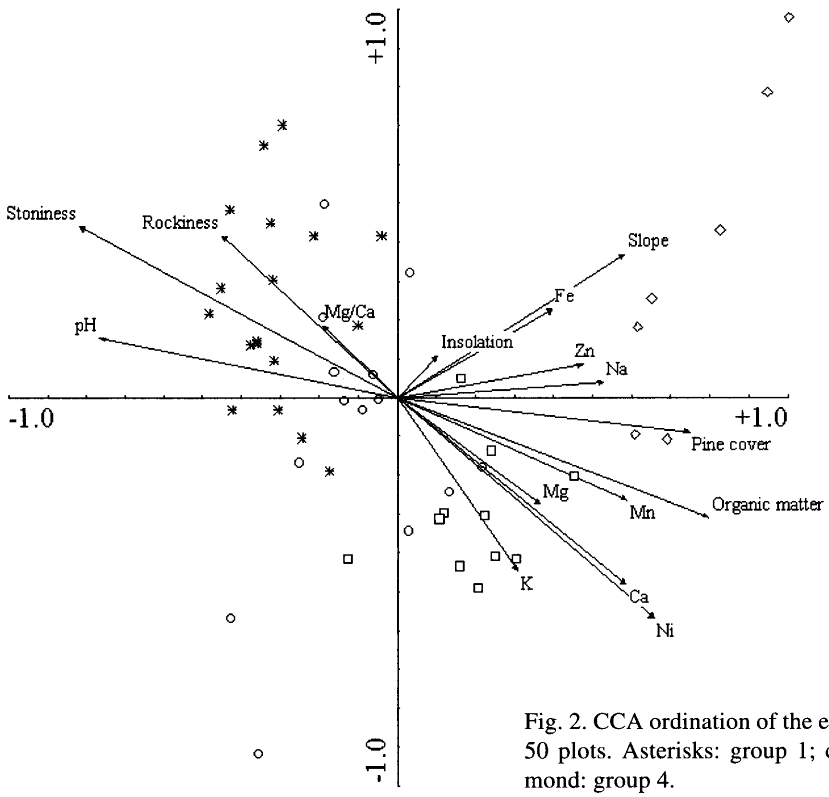


Fig. 2. CCA ordination of the environmental variables analyzed and the 50 plots. Asterisks: group 1; circles: group 2; squares: group 3; diamond: group 4.

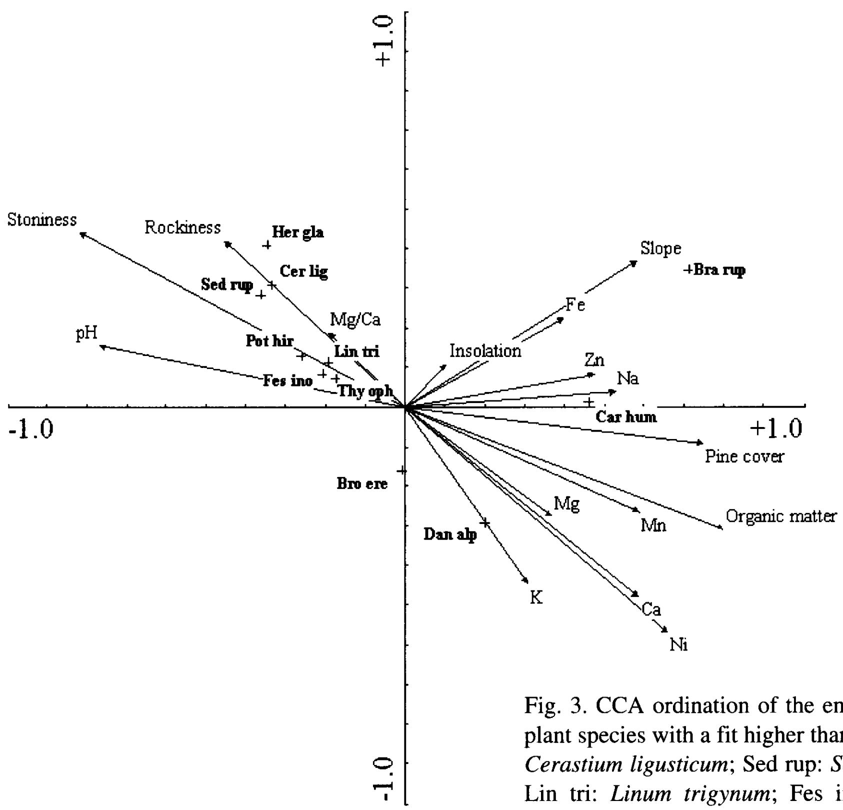


Fig. 3. CCA ordination of the environmental variables analyzed and the plant species with a fit higher than 25. Her gla: *Herniaria glabra*; Cer lig: *Cerastium ligusticum*; Sed rup: *Sedum rupestre*; Pot hir: *Potentilla hirta*; Lin tri: *Linum trigynum*; Fes ino: *Festuca inops*; Thy oph: *Thymus acycularis* ssp. *ophioliticus*; Bro ere: *Bromus erectus*; Dan alp: *Danthonia alpina*; Car hum: *carex humilis*; Bra rup: *Brachypodium rupestre*.

Table 5
Correlations of environmental variables with the first two axes of CCA ordination

| Environmental variable | Axis 1 | Axis 2 |
|---|---|---|
| Slope | 0.5527 | 0.3037 |
| Normalized insolation | 0.0999 | 0.0884 |
| Rockiness | –0.4261 | 0.3441 |
| Stoniness | –0.7741 | 0.3619 |
| Pine cover | 0.7107 | –0.0755 |
| LOI | 0.7567 | –0.2567 |
| pH | –0.7247 | 0.1272 |
| Zn | 0.4535 | 0.0696 |
| Ni | 0.6242 | –0.4666 |
| Fe | 0.3788 | 0.1876 |
| Mn | 0.5568 | –0.2193 |
| Mg | 0.3504 | –0.2290 |
| Ca | 0.5545 | –0.3965 |
| Na | 0.5006 | 0.0335 |
| K | 0.2952 | –0.3681 |
| Ca/Mg | –0.1800 | 0.1540 |

## DISCUSSION

The present survey enabled four main types of grassland and dwarf shrub vegetation to be distinguished in Monte Ferrato, one of which, the *Danthonia alpina* grasslands, has never previously been reported. As found in other recent studies of Tuscan ultramafic soils (Angelone et al., 1991, 1993) and vegetation (Chiarucci and De Dominicis, 1995; Chiarucci, 1998a,b), the influence of soil metal content on plant communities is not as great as other ecological factors, such as water and nutritional stress. Moreover, the chemical features found to be correlated with the vegetation pattern should not be considered the cause, but partially the effect of vegetation dynamics, which strongly influence soil development. In this sense, soil and vegetation processes and dynamics influence each other by positive feedback.

Pine cover was found to be one of the most important factors influencing vegetation. As found in another ultramafic site, pine cover can improve plant diversity and cover, probably by protecting the soil from splash erosion and providing an additional nutrient input (Chiarucci and De Dominicis, 1995; Chiarucci, 1996). This input may be related to pine cover in a direct (needles, branches, and bark fall) and indirect (higher interception of wet and dry deposition from atmosphere) ways. In the Monte Ferrato area, pines were introduced at the beginning of this century and reproduced readily (Messeri, 1936) especially in the xeric grasslands, which are probably one of the most natural vegetation types in this area.

Another important factor influencing the present vegetation of Monte Ferrato may be the increased atmospheric nitrogen input due to pollution from the cities of Florence, Prato, and Pistoia. Increased atmospheric nitrogen input due to pollution has been found to promote dominance of *Brachypodium pinnatum* and reduce species diversity in oligotrophic vegetation types, such as chalk grasslands (Bobbink and Willems, 1987; Bobbink, 1991; Willems et al., 1993). *Brachypodium rupestre*, which is vicariant of *B. pinnatum* in almost all of Italy, was once rare in the Monte Ferrato area (Messeri, 1936) and may have spread in recent times because of eutrophication due to the pine canopy and increased atmospheric nitrogen input.

The conservation of the ultramafic vegetation of Monte Ferrato, with its typical barren appearance and its richness in Tuscan serpentine endemics, is probably endangered by the spread of the pines and by pollution. Both these factors should be monitored and possibly reduced. The reduction of pollution is generally desired but difficult to achieve quickly. However a reduction in the spread of pines is a practical possibility at least in some parts of the area. Without a control, and possibly a reduction of pines, their presence could increase since they colonize xeric grasslands well, and vegetation structure and composition of this site of great ecological interest are likely to be modified.

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