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Diversity, geographic variation and conservation of the serpentine flora of Tuscany (Italy)

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Abstract. The specialised flora of serpentine outcrops in Tuscany (Italy) is analysed in terms of species richness and geographic variation, in order to identify main centres of diversity and provide a basis for conservation programmes. Five edaphic groups are distinguished, among which obligate endemics, serpentine-preferential taxa, facultative basiphilous and facultative calcifuge serpentinophytes. Relatively low diversity (87 taxa) and high taxonomic distinctiveness (28.7% of endemics plus preferentials) underscore the insular condition of the ophiolitic outcrops. Hemicryptophytes and chamaephytes are the dominat life-forms, in line with the mainly continental character revealed by the phytogeographical analysis. Presence/absence of the taxa in 10 serpentine island systems was assessed using literature and original field data. Number of species and surface of the areas are significantly correlated. Cluster analysis identifies five groups of areas, while ordination indicates the species which are more effective in determining the floristic differences among the areas. Cecina valley, Monte Ferrato, Murlo hills and upper Tiber valley are the main centres of endemism and taxonomic diversity. However, the positive relationship between floristic and geographic distances and the remarkable proportion of species with frequency <50% highlights a considerable among-area variation. To 'catch' such variation, a network of distant protected sites appears more effective than to search for single areas with high diversity. At least one site in each of the five clusters should be included in a 'Important Plant Area' network which would ensure the conservation of such a peculiar component of the Italian vascular flora.

Introduction

Serpentine soils originate from different types of ophiolitic rocks and are known since long time to represent a strongly hostile environment for plant life due to severe anomalies in their chemical and physical properties. These include: (1) calcium:magnesium ratios less than 1.0, (2) nutrient deficiency, especially in nitrogen and phosphorus, (3) phytotoxic concentrations of cobalt, chromium and especially nickel, (4) pH values from basic to ultrabasic, and (5) slow rock weathering (Brooks 1987). A marked heating under sunny conditions and a rapid loss of humidity further contribute to render the serpentine a selective habitat and thus a major driving force for plant evolution. Indeed, only a small part of the plant taxa of a regional flora is adapted to grow under these constraints and these are called 'serpentinophytes'. According to Kruckeberg (2002), serpentinophytes can be categorised into three main types:

(1) narrowly endemic taxa restricted to a local or regional outcrop(s), (2) non-obligate but preferential serpentine taxa, with a wide distribution but often restricted to serpentine in part of their ranges, (3) taxa frequently occurring on serpentine as well as on a broad variety of other bedrocks (the so-called 'bodenvag' species, Kruckeberg 2002).

Ophiolitic outcrops often occur in the form of ecological 'edaphic' islands (Harrison and Inouye 2002), and are usually populated by distinctive plant communities with a mixture of taxa of the three groups mentioned above.

In Europe, the main centres of diversity lie in the Balkans, with about 335 endemics of which 123 obligate taxa (Stevanović et al. 2003) and, to a lesser extent, in Italy (Vergnano Gambi 1992). Italian serpentine 'islands' range from the central-western Alps to the northern Apennines and especially in the region of Tuscany (22.992 km^2), where several outcrops are scattered in different biogeographic sectors (Abbate and Bortolotti 1984). The greatest concentration is found in the tyrrhenian hills of the Pisa, Siena and Livorno provinces, while others are located more inland, such as those in the Arezzo and Firenze provinces. The flora of these outcrops is today sufficiently known thanks to a series of studies which have been carried out in single areas, in particular the upper Tiber valley (Pichi Sermolli 1948), Monte Ferrato (Arrigoni 1974) and Cecina valley (Selvi and Bettini 2004); a brief synthesis was provided by Chiarucci and De Dominicis (2001). To date, however, no attempts have been made to analyse species diversity and geographic variation of the regional serpentine flora, though this is the first step to identify the sites which may be recognised as 'Important Plant Areas' (IPAs) under the European Plant Conservation Strategy (Palmer and Smart 2001). Yet, conservation intiatives of the Italian serpentine flora are urgent because the relatively limited extent and isolation of the ophiolitic outcrops exposes many rare and endemic species to a serious threat in case of environmental changes and stochastic events driven by human activities (e.g. mining). Many plant species inhabiting this habitat have a naturally fragmented range, and factors that will cause any further reduction of the populations are likely to lead to critical demographic thresholds. After a brief description of the taxonomic, structural and phytogeographical elements in five edaphic groups of the regional serpentine flora, the present paper uses numerical methods to analyse geographic variation and identify the areas which harbour the greatest phytotaxonomic diversity and concentration of endemic plants.

Material and methods

Collection of the data

A data-base of the taxa recorded for the garrigue-like vegetation of Tuscan serpentine soils was compiled combining reliable literature data and observations from personal field researches carried out over the last 10 years. Main reference lists for this compilation were Pichi Sermolli (1948), Arrigoni (1974), Chiarucci et al. (1995, 1998) Ferrarini et al. (1997–2000) and Selvi and Bettini 2004). A selection was made of only those taxa appearing in the association *Armerio denticulatae–Alyssetum bertolonii* Arrigoni, Mazzanti & Ricceri, e.g. the most typical community of scattered, pioneer plants which colonise the rocky outcrops of serpentine or mixed serpentine/diabase. Species occurring in other types of more evolved serpentine vegetation, such as woods, dense matorrals, conifer plantations and dense grasslands, were instead excluded, as well as those appearing in anthropogenically disturbed areas.

Mainly following the classification proposed by Stevanović et al. (2003), the recorded taxa were grouped in five categories based on their observed edaphic preferences in Tuscany. Minor modifications were adopted to better describe the edaphic variation at the regional level and to allow a more precise analysis of life-forms and phytogeographical elements. Adopted categories are: (1) obligate serpentinophytes, e.g. endemic taxa exclusively found on regional outcrops; (2) preferential serpentinophytes, e.g. taxa restricted to serpentine at the regional level but eventually growing also on different substrates in other parts of their range (mainly non-endemics); (3) facultative basiphilous serpentinophytes, e.g. taxa frequently found on serpentine but also on calcareous or calcareous/dolomitic bedrocks; (4) facultative calcifuge serpentinophytes, e.g. taxa frequently found on serpentine and on other types of siliceous bedrock; (5) taxa substantially 'indifferent' to the substrate, frequently occurring on serpentine and other soil types of the region, either calcareous or non-calcareous ('bodenvag' taxa *sensu* Kruckeberg 2002). The numerous 'occasional' species found on serpentine only sporadically or very locally have been excluded from the present analysis. Nomenclature follows Pignatti (1982), but is updated according to Conti et al. (2005).

The following data were recorded for each taxon: life-form, chorotype basically according to Pignatti (1982) with very minor modifications, IUCN conservation category at either the regional or national level (based on Conti et al. 1997, and on more recent lists from Regione Toscana) and presence/absence in the 10 main regional serpentine insular systems. These are (Figure 1): Cecina valley (VCE), Riparbella hills (RIP), Livorno hills (LIV), Pievescola hills (PIE), Murlo hills (MUR), Monte Ferrato (FER), Impruneta (IMP), Upper Tiber valley (TIB), Sarzana hills (SAR) and Roccatederighi (ROC). Altitude ranges between 150 and 600 m a.s.l. Distances between the 10 areas ranges between a minimum of about 15 km (LIV-RIP) and a maximum of about 176 km (SAR-TIB). The approximate surface of the serpentine outcrops in the above areas was measured from the 1:100,000 geological maps of Italy using a LI-3100 Area meter (LI-COR, USA).

Analysis of the data

Taxonomic diversity, life-forms, phytogeographical elements and number of taxa listed in national or regional Red Data Books were analysed for each

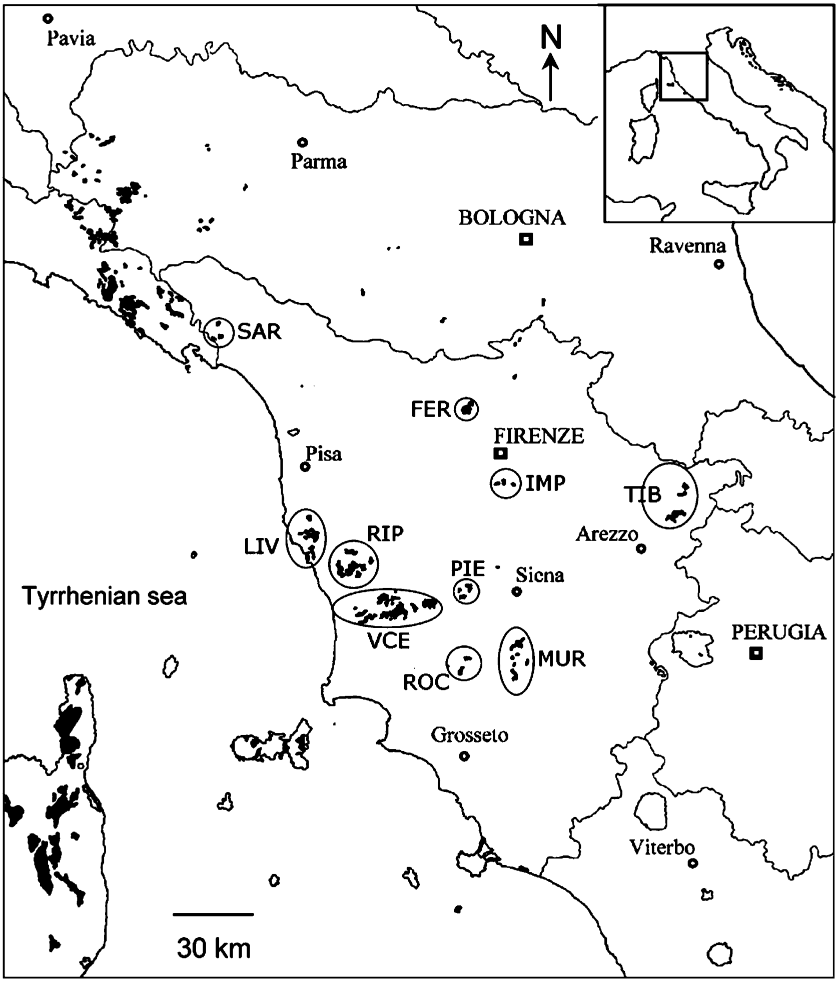

Figure 1. Study area with location of the 10 serpentine 'insular' systems in Tuscany: FER, Monte Ferrato; IMP, Impruneta; LIV, Livorno hills; MUR, Murlo hills; PIE, Pievescola hills; RIP, Riparbella hills; ROC, Roccatederighi; SAR, Sarzana hills; TIB, Upper Tiber valley; VCE, Cecina valley.

edaphic group. Non-parametric Spearman rank correlation coefficients were used to investigate the relationship between number of species and surface of the serpentine outcrops in the 10 areas. Such correlation was calculated separately for the total number of taxa in the five groups and for the number of obligate endemics plus the preferentials. Multivariate methods were then used to summarise the relationships of floristic affinity between the areas and to evaluate the role of the variables (taxa) in their separation. To this purpose, the presence/absence matrix taxa vs. areas was subjected to hierarchial agglomerative cluster analysis using Euclidean distance and Uweighted Pair Group

Average (UPGMA) as computational criteria. Mantel's test was used to analyse the correlation between the matrix of floristic distances and that of the logarithmically-transformed geographical distances between the areas obtained as edge-to-edge nearest neighbor distance (Harrison and Inouye 2002); normalised Mantel Z statistics was calculated after 1000 permutations. Ordination by Principal Component Analysis (PCA) then allowed to detect the main sources of variation within the data set, to display the results in a non-hierarchical way and to show the relationships between areas and variables (Taggart 1994). Eigenvalues were extracted from the correlation matrix. All multivariate analyses were performed using the NTSYS package as implemented in the 2.1 version (Rohlf 2000). Scoring the area groups identified by the multivariate analyses in terms of number of taxa in each ecological group allowed to evaluate the geographical distribution of such groups and the identification of the regional areas harbouring the greatest diversity of mainly endemics and preferential serpentinophytes.

Results

Diversity, phytogeographical elements and life-forms of the edaphic groups

Obligate serpentinophytes include nine dicot and two monocot species, most of which are restricted to Tuscany (Table 1). The Nickel-hyperaccumulator *Alyssum bertolonii* ssp. *bertolonii* and the herbs *Minuartia laricifolia* ssp. *ophiolitica* and *Thymus striatus* ssp. *ophioliticus* have a slightly broader range reaching also the northern Apennines and the Ligurian hills. While *Biscutella pichiana* and *Leucanthemum pachyphyllum* have a discontinuous distribution, *Armeria denticulata*, *Stipa etrusca* and *Festuca robustifolia* occur in most of the regional outcrops; the latter species is here considered a Tuscan serpentine endemic in accordance with Foggi and Signorini (2001). Only the chamaephytic and hemicryptophytic life-forms are represented within this category, while therophytes are completely lacking. Three taxa are listed in the 'Lower Risk' category of the National Red list while seven appear in the regional list, one of which in the 'Endangered' category.

Preferential serpentinophytes are represented by 13 species and one subspecies which show a clear preference for serpentine, though not restricted to this soil in other parts of their range (Table 2). Those with the wider distribution and higher frequency are *Genista januensis*, *Juniperus oxycedrus* ssp. *oxycedrus*, *Plantago holosteum* and *Carex humilis*, while *Euphorbia epithymoides* aggr., *Centaurea paniculata* ssp. *lunensis* and *Stipa tirsa* are restricted to single areas. Hemicryptophytic herbs and small shrubs (chamaephytes) are again the dominant life-forms. The prevalence of the SE European, Eurasian and Eurosiberian chorotypes over the Mediterranean ones is in line with this finding, indicating the mainly continental and steppic character of this ecological group. From a conservation viewpoint, 50% of the taxa appear in the

Table 1. Life-form, chorotype (end = endemic), frequency in the 10 areas examined and IUCN category (R: Regional level, N: National level) of the Tuscan obligate serpentinophytes.

Taxa	Life-form[a]	Chorotype	Freq. %	IUCN
Alyssum bertolonii Desv. ssp. *bertolonii*	Chsuffr	End. TU, ER, LIG[b]	100	VU (R)
Armeria denticulata Bertol.	Hros	End. TU	100	LR (R)
Biscutella pichiana Raffaelli ssp. *pichiana*	Hscap	End. TU	30	VU (R)
Centaurea paniculata L. ssp. *carueliana* (Micheletti) Arrig.	Hscap	End. TU	80	VU (R)
Euphorbia nicaeensis All. ssp. *prostrata* (Caruel) Arrig.	Chsuffr	End. TU	70	EN (R)
Festuca robustifolia Markgr.-Dann.	Hcaesp	End. TU	90	–
Leucanthemum pachyphyllum Marchi & Illum.	Hscap	End. TU	40	LR (N)
Minuartia laricifolia (L.) Schinz & Thell. ssp. *ophiolitica* Pign.	Chsuffr	End. TU, ER, LIG	30	LR (N)
Stachys recta L. ssp. *serpentinii* (Fiori) Arrig.	Hscap	End. TU	80	LR (N)
Stipa etrusca Moraldo	Hcaesp	End. TU	70	LR (R)
Thymus striatus Vahl ssp. *ophioliticus* Lacaita	Chsuffr	End. TU, ER	90	LR (R)

[a]Main form: H = Hemicryptophyte; Ch = Chamaephyte; T = Therophyte; G = Geophyte; P = Phanerophyte. Subform: suffr = suffruticose; caesp = caespitose; scap = scapose; bulb = bulbous; ros = rosulate.
[b]ER: Emilia-Romagna; LIG: Liguria; TU: Tuscany.

regional list under the VU and LR categories; the only endemic, *Centaurea paniculata* ssp. *lunensis*, is listed as ‘Critically Endangered’.

Facultative basiphilous serpentinophytes growing on serpentine or limestone are linked to basic soils but are substantially indifferent to the amount of Ca in

Table 2. Life-form (legend in Table 1), chorotype, frequency in the ten areas examined and IUCN category (R: Regional level, N: National level) of the Tuscan preferential serpentinophytes.

Taxa	Life-form	Chorotype	Freq. %	IUCN
Artemisia alba Turra	Chsuffr	SE. European	50	VU (R)
Asplenium cuneifolium Viv.	Hros	Mid-European	20	LR (R)
Carex humilis Leyss.	Hcaesp	Eurasian	70	–
Centaurea paniculata L. subsp. *lunensis* (Fiori) Arrig.	Hscap	Endemic TU	10	CR (R)
Cytisus decumbens (Durande) Spach	Chsuffr	S. European	20	VU (R)
Euphorbia epithymoides L. (aggr.)[a]	Hscap/Grhiz	SE. European	10	–
Genista januensis Viv.	Chsuffr	SE. European	100	–
Iberis umbellata L.	Tscap	N. Mediterr.	50	–
Juniperus oxycedrus L. subsp. *oxycedrus*	Pcaesp	Euro-Mediterr.	100	–
Notholaena marantae (L.) Domin	Hros	Paleosubtrop.	60	LR (R)
Onosma echioides L.	Chsuffr	SE. European	40	–
Plantago holosteum Scop.	Hros	SE. European	80	–
Scorzonera austriaca Willd.	Hros	SE. European	40	LR (R)
Stipa tirsa Steven	Hcaesp	Eurosiberian	10	LR (R)

[a]The taxonomic identity of the populations of the *E. epithymoides* aggr. occurring in NW Tuscany (SAR area, Ferrarini et al. 1997) could not be checked and requires further investigation.

the substrate. *Potentilla hirta* ssp. *hirta*, *Anthyllis vulneraria* ssp. *rubriflora*, *Silene paradoxa*, *Bromus erectus*, *Galium corrudifolium*, *Trinia glauca*, *Koeleria splendens* and *Dianthus sylvestris* ssp. *longicaulis* are among the most frequent of this category in Tuscany (Table 3). Only two taxa have a special conservation relevance, e.g. *Allium moschatum* and *Linum austriacum* ssp. *tommasinii*, which are known for only two or three small populations isolated on some of the westernmost serpentine outcrops; over the rest of their range they are always found on calcareous soils. Dominant life-forms are again hemicryptophytes and chamaephytes, while it is of outstanding ecological relevance the total lack of annual plants. Phytogeographically, the European s.l. element, especially southeastern, is again dominant over the Mediterranean one, which is represented by five species mainly distributed in the northwestern part of the basin.

Facultative calcifuge serpentinophytes growing on siliceous bedrocks have the unusual ability to tolerate the basic or ultrabasic pH values of serpentine

Table 3. Life-form (legend as in Table 1), chorotype, frequency in the 10 areas examined and IUCN category (R: Regional level, N: National level) of the facultative basiphilous serpentinophytes frequently found on calcareous (or calcareous-dolomitic) bedrocks.

Taxa	Life-form	Chorotype	Freq. %	IUCN
Allium moschatum L.	Gbulb	SE. European	20	VU (R)
Alyssum montanum L.	Chsuffr	C. European-Pontic	60	–
Anthyllis vulneraria L. ssp. *rubriflora* (DC.) Arcang.	Hscap	Euro-Mediterr.	90	–
Antirrhinum latifolium Mill.	Hscap	NW. Mediterr.	10	–
Bromus erectus Huds.	Hcaesp	Paleotemp.	100	–
Campanula medium L.	Hscap	NW. Medit-Mont.	20	LR (R)
Centaurea rupestris L. ssp. *rupestris*	Hscap	SE. European	10	–
Danthonia alpina Vest	Hcaesp	SE. European	40	–
Dianthus sylvestris Wulf. ssp. *longicaulis* (Ten.) Greuter & Burdet	Hscap	W. Medit-Mont.	90	–
Euphorbia spinosa L. ssp. *spinosa*	Chsuffr	N. Mediterr.	30	–
Fumana procumbens (Dunal) Gren. & Godr	Chsuffr	Euro-Medit-Pontic	70	–
Galium corrudifolium Vill.	Hscap	Steno-Mediterr.	100	–
Globularia punctata Lapeyr.	Hscap	SE. European	20	–
Hippocrepis comosa L.	Hscap	CS. European	30	–
Iris lutescens Lam	Grhiz	NW. Mediterr.	40	–
Koeleria splendens Presl	Hscap	Medit.-Mont.	80	–
Linaria purpurea (L.) Mill.	Hscap	Apenninic (Endem)	40	–
Linum austriacum L. ssp.*tommasinii* (Rchb.) Greuter & Burdet	Hscap	SE. European	30	EN (R)
Linum tenuifolium L.	Chsuffr	Euro-Medit-Pontic	60	–
Potentilla hirta L ssp. *hirta*	Hscap	W. Medit-Europ.	100	–
Saponaria ocymoides L.	Hscap	SW. Europ-Mont.	40	–
Silene paradoxa L.	Hscap	N. Medit-Mont.	100	–
Stahelina dubia L	Chsuffr	W. Mediterr.	40	–
Teucrium montanum L.	Chsuffr	S. European-Mont.	50	–
Trinia glauca (L.) Dumort.	Hscap	SE. European	70	–

soils. Based on our data, only 11 species show this type of 'bipolar' edaphism, among which the shrubs *Genista pilosa*, *Myrtus communis*, *Erica arborea* and *E. scoparia*, the herbs *Jasione montana*, *Hypochoeris glabra* and *Silene armeria* and the grass *Molinia arundinacea* (Table 4). The Mediterranean component is here more represented than in the other groups, while the more continental elements (e.g. the SE European) are almost lacking.

Finally, 26 taxa are frequent on serpentine as well as on a broad variety of different bedrocks in Tuscany (Table 5). Examples are *Festuca inops*, *Herniaria glabra*, *Sanguisorba minor*, *Sedum rupestre*, *Sedum album*, *Helichrysum italicum*, *Phillyrea latifolia* and *Cerastium ligusticum*. The only species in this group with a remarkable conservation value due to its rarity at the national level (listed as VU in the Red List) is the geophyte *Tulipa australis*, which appears with conspicuous populations in the westernmost outcrops. Also this group includes mainly perennial life-forms (22), the majority of which are hemicryptophytes; there is again evidence that annual species are a minor component of the regional serpentine flora (four taxa). Phytogeographically, this group is poorly characterised and comprises several taxa with a vast range of subcosmopolitan or paleotemperate type.

Area groups and geographic variation

A highly significant relationship occurs between surface of the serpentine outcrops in the ten areas and total number of species in the five edaphic groups (Spearman $r = 0.92$; p-level $= 0.00014$; Figure 2a). The number of obligate endemics and preferential taxa is also positively associated with the surface of the areas, though to a lesser extent (Spearman $r = 0.76$; p-level $= 0.012$; Figure 2b).

Table 4. Life-form (legend as in Table 1), chorotype, frequency in the ten areas examined and IUCN category (R: Regional level, N: National level) of the facultative calcifuge serpentinophytes frequently found on other siliceous substrates.

Taxa	Life-form	Chorotype	Freq. %	IUCN
Aira elegantissima Schur.	Tscap	Euro-Mediterr.	70	–
Arbutus unedo L.	Pcaesp	Steno-Mediterr.	80	–
Erica arborea L.	Pcaesp	Steno-Mediterr.	100	–
Erica scoparia L.	Pcaesp	W. Mediterr.	100	–
Euphorbia verrucosa L.	Hscap	S. European-Pontic	30	–
Genista pilosa L.	Chsuffr	Mid-European	70	–
Hypochoeris glabra L.	Tros	Euro-Mediterr.	40	–
Jasione montana L.	Tscap	Europ.-Caucas.	40	–
Molinia arundinacea Schrank	Hcaesp	Europ.-Caucas.	60	–
Myrtus communis L.	Pcaesp	Steno-Mediterr.	80	–
Silene armeria L.	Tscap	Mid-European	50	–

Table 5. Life-form (legend as in Table 1), chorotype, frequency in the 10 areas examined and IUCN category (R: Regional level, N: National level) of the edaphically 'indifferent' taxa frequently occurring on Tuscan serpentine soils and other bedrocks.

Taxa	Life-form	Chorotype	Freq. %	IUCN
Allium sphaerocephalon L.	Gbulb	Paleotemp.	80	–
Anthericum liliago L.	Gbulb	SubMedit.–SubAtlant.	60	–
Arenaria serpyllifolia L.	Tscap	Subcosmop.	50	–
Asperula cynanchica L.	Hscap	Euro-Mediterr.	60	–
Asplenium adiantum-nigrum L.	Hros	Paleotemp-Subtropic.	100	–
Brachypodium rupestre Roem. & Schult.	Hcaesp	SubAtlant.	60	–
Buxus sempervirens L.	Pcaesp	SubMedit-SubAtlant.	20	–
Cerastium ligusticum Viv.	Tscap	W. Mediterr.	80	–
Cistus salvifolius L.	NP	Steno-Mediterr.	80	–
Convolvulus cantabrica L.	Hscap	Euro-Mediterr.	80	–
Dorycnium hirsutum (L.) Ser.	Chsuffr	Euro-Mediterr.	70	–
Echium vulgare L.	Hbienn	European	60	–
Festuca inops De Not.	Hcaesp	Apenninic (Endem.)	100	–
Helichrysum italicum G. Don.	Chsuffr	S. European	100	–
Herniaria glabra L.	Trept	Paleotemp.	100	–
Leontodon villarsii (Willd.) Loisel.	Hros	NW. Mediterr.	60	–
Linum trigynum L.	Tscap	Euro-Mediterr.	50	–
Phillyrea latifolia L.	Pcaesp	Steno-Mediterr.	90	–
Reichardia picroides (L.) Roth	Hscap	Steno-Mediterr.	40	–
Rhamnus alaternus L.	Pcaesp	Steno-Mediterr.	90	–
Sanguisorba minor Scop.	Hscap	Subcosmop.	100	–
Scrophularia canina L.	Hscap	Euro-Mediterr.	40	–
Sedum album L.	Chsucc	Euro-Mediterr.	100	–
Sedum rupestre L.	Chsucc	CW. European	100	–
Tulipa australis Link	Gbulb	NW. Medit-Mont.	40	VU (N)
Vincetoxicum hirundinaria Medicus	Hscap	Eurasian	80	–

The UPGMA dendrogram resulting from the cluster analysis of the areas based on the presence/absence of the 87 taxa of the five edaphic groups is shown in Figure 3. At a similarity coefficient of 0.56 the 10 areas form five clusters which can be interpreted in terms of geographical location. Results of the Mantel test indicate a significant correlation ($r = 0.64$; $p < 0.01$) between floristic and log-transformed geographical distances between the outcrops.

In the dendrogram, a first group comprises the three western areas (VCE, LIV, RIP) which lie close to the tyrrhenian coastline in a meso-mediterranean climatic belt (Barazzuoli et al. 1993). They harbour the greatest number of obligate endemics plus preferential serpentinophytes, especially VCE (21, Table 6). Also in relation to its remarkable extent (*c*. 35 km^2), the latter area is also rich in facultative basiphilous, facultative calcifuge and 'bodenvag' serpentinophytes, and this accounts for its divergent position in the dendrogram. This area group, and particularly VCE, contains the highest number of taxa (37) listed in regional and/or national red lists (Figure 4).

The second group, formed by FER and IMP, differs mainly in the lack of some preferential and facultative basiphilous serpentinophytes such as *Onosma*

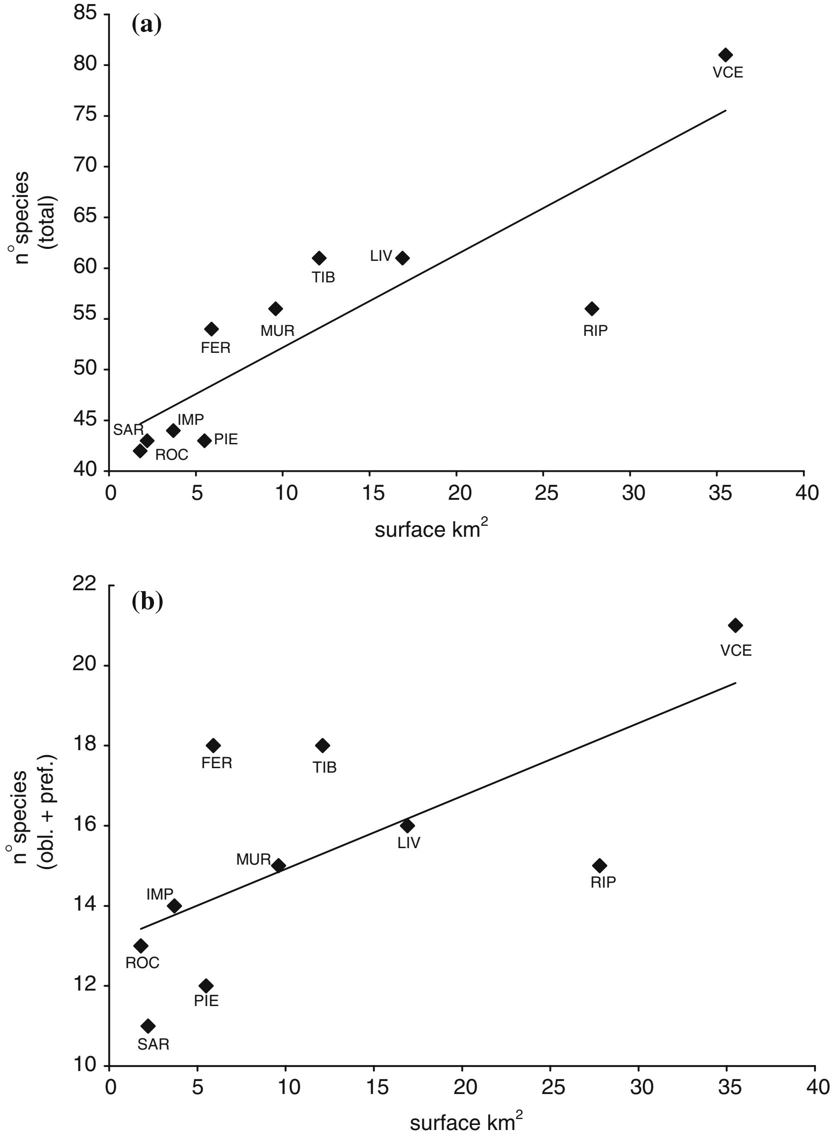

Figure 2. Relationship between surface (km^2) of the serpentine areas and number of serpentine species. (a) Total number recorded in the five ecological groups; (b) number of obligate endemics plus serpentine-preferential taxa. Area codes follow legend to Figure 1 and text.

echioides, *Cytisus decumbens* and *Iberis umbellata* (pref.) and *Euphorbia spinosa*, *Iris lutescens* and *Allium moschatum* (basiph.). The FER area is richer than IMP in relation to its greater extent, and the number of obligate endemics found at this site (10) is the highest in Tuscany as for VCE in group 1.

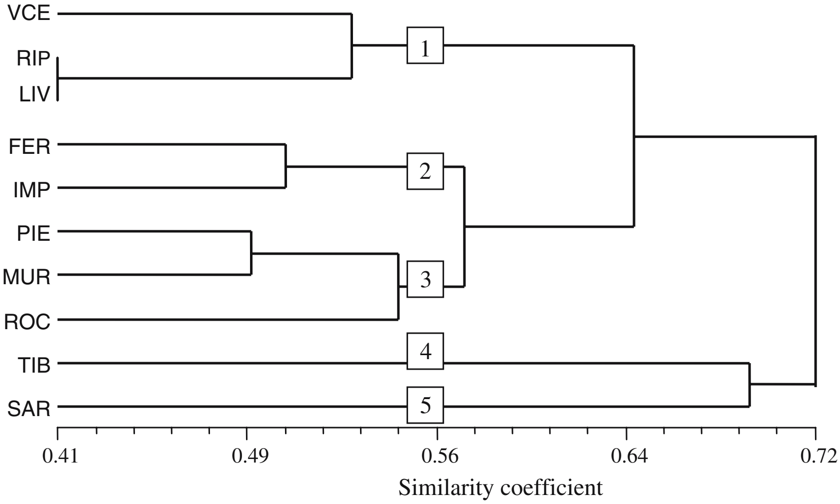

Figure 3. UPGMA dendrogram of the the 10 areas based of floristic affinity. Clusters described in the text are numbered (1–5). Area codes follow legend to Figure 1 and text.

Group 3 is formed by PIE, MUR and ROC, three areas lying in the central-southern part of the region. It contains a lower number of both 'red list' species and serpentinophytes, either obligate or preferential. Examples of such taxa apparently lacking here are *Minuartia laricifolia* ssp. *ophiolitica* and *Biscutella pichiana* among the endemics, and *Artemisia alba* among the preferentials. ROC, the smallest outcrop, is somewhat floristically divergent due to its southernmost location; for example it harbours *Leucanthemum pachyphyllum*, which is not recorded for PIE and MUR, but it lacks two obligate endemics with a 70% frequency, such as *Euphorbia nicaeensis* ssp. *prostrata* and *Stipa etrusca*.

Group 4 is formed by only TIB, the easternmost area located in the upper Tiber valley at the foot of the Apennine range. With respect to the others, it lies in a more continental biogeographic sector and is therefore floristically divergent. In spite of its isolation, however, it has been successfully colonised by most of the typical serpentinophytes, among which the rare pteridophyte *Asplenium cuneifolium* (obligate) and the grass *Stipa tirsa* (preferential); the only endemics which are lacking are *Biscutella pichiana*, *Centaurea paniculata* ssp. *carueliana* and *Euphorbia prostrata* ssp. *nicaeensis*.

Finally, SAR is a small outcrop geographically isolated at the extreme north of the region and these factors account for the reduced number of obligate endemics (*Armeria denticulata* and *Alyssum bertolonii*). On the other hand, it harbours the only regional serpentine populations of *Buxus sempervirens*, *Euphorbia epithymoides* and *Centaurea paniculata* ssp. *lunensis*, endemic and listed as 'Critically Endangered' at the regional level.

Ordination of the data set using Principal Component Analysis accounts for 63.9% with the first three components. Percentage eigenvalues and factor

Table 6. Quantitative distribution (number of taxa) of the five edaphic groups in the 10 areas. Area codes as in Figure 1 and text.

Areas	Edaphic groups				
	1. Oblig. end.	2. Preferent.	3. Facult.-bas.	4. Facult.-calcif.	5. Indiff.
FER	10	8	11	7	18
IMP	9	5	10	6	14
LIV	9	7	18	7	20
MUR	7	8	12	8	21
PIE	7	5	10	6	15
RIP	8	7	16	5	20
ROC	7	6	10	6	14
SAR	2	9	12	7	13
TIB	8	10	14	9	20
VCE	10	11	24	11	25

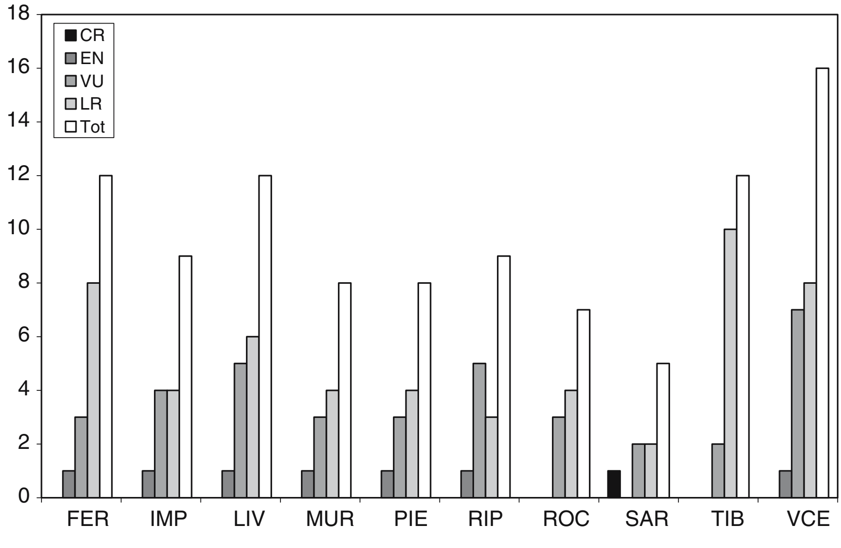

Figure 4. Number of taxa in the 10 serpentine areas listed under one of the IUCN conservation categories at the regional or national level. Area codes follow legend to Figure 1 and text.

loadings on these axes are reported in Table 7. Plotting the first against the second axis (Figure 5) produces a two-dimensional scattergram of the areas that can be interpreted in terms of the most important variables (taxa) accounting for their floristic separation. Only those variables with correlations ≥ 0.7 with at least one of the two components are plotted, and this results in the exclusion of 67 less informative variables and in the identification of the 20 taxa which are more significant in determining the position of the areas in the biplot. All of the five edaphic groups here distinguished are involved in this, and none

Table 7. Percentage eigenvalues, variance explained by the first three components and factor loadings of the twenty variables (taxa) with correlation ≥0.7 on at least one of the first two components.

	Taxon code	1	2	3
Eigenvalue (%)		26.8	19.7	17.4
Cumulative (%)		26.8	46.5	63.9
Variables (taxa)				
Alyssum montanum	Aly	−0.82	−0.23	−0.18
Arbutus unedo	Arb	−0.76	−0.42	0.39
Asperula cynanchica	Asc	−0.72	0.04	0.05
Biscutella pichiana	Bis	−0.78	0.32	−0.39
Buxus sempervirens	Bux	0.75	0.42	−0.39
Centaurea paniculata ssp. carueliana	Cpc	−0.76	−0.42	0.39
Centaurea paniculata ssp. lunensis	Cpl	0.70	−0.14	−0.74
Euphorbia epithymoides	Eue	0.70	−0.14	−0.74
Euphorbia spinosa	Eus	−0.78	0.32	−0.39
Hippocrepis comosa	Hip	−0.14	0.84	0.17
Iris lutescens	Iri	−0.78	0.32	−0.40
Linaria purpurea	Lip	−0.49	0.72	−0.23
Linum austriacum ssp. tommasinii	Lat	−0.60	0.42	−0.12
Linum trigynum	Ltr	−0.82	0.01	−0.25
Minuartia laricifolia ssp. ophiolitica	Min	0.15	0.82	0.33
Onosma echioides	Ono	−0.84	0.21	−0.34
Scorzonera austriaca	Sco	−0.27	0.84	−0.15
Scrophularia canina	Scr	−0.49	0.72	−0.23
Stipa tirsa	Sti	0.38	0.70	0.22
Tulipa australis	Tul	−0.85	0.22	−0.34

of these groups can account alone for the separation of the areas. However, the obligate endemics (three) plus the preferential serpentinophytes (five) are, proportionally to their total number (25; 32%), more represented than both the facultative (six basiphilous serp. and one calcifuge serp., which corresponds to *c*. 19%) and the edaphically indifferent taxa (five, 19%). Among the endemics, for example, *Biscutella pichiana* is strongly correlated with the western areas of cluster no. 1 (VCE, LIV, RIP), while *Minuartia laricifolia* ssp. *ophiolitica* 'follows' more the two continental areas FER and TIB. Among the preferentials, *Scorzonera austriaca* is correlated with the areas of cluster no. 2 (FER, IMP), while the south-central areas of cluster no. 3 (MUR, PIE, ROC) are associated with the two edaphically indifferent species *Linum tryginum* and *Asperula cynanchica*. The northernmost area SAR is clearly near to the two preferentials *Centaurea paniculata* ssp. *lunensis* and *Euphorbia epithymoides*, as well as to *Buxus sempervirens*.

Discussion

The restrictive criteria adopted for the purposes of this study led to the selection of a number of taxa (87) remarkably lower with respect to the

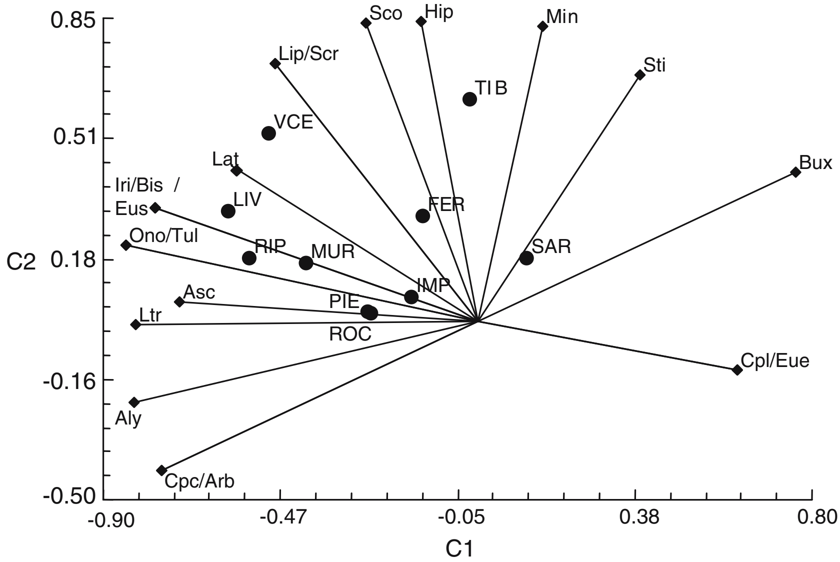

Figure 5. Principal Component Analysis biplot of areas (black dots) and variables (vectors). C1, first component; C2, second component. Length of the vectors is proportional to the strength of the correlation between variables and one of the components. Area codes follow legend to Figure 1 and text. Variables (taxa) codes as in Table 7.

estimation (809 taxa) by Chiarucci and De Dominicis (2001), who included all the species recorded on serpentine regardless of their edaphism, frequency and vegetation type. Although our selection represents only a minor part (2.5%) of the Tuscan vascular flora (3435 taxa, Conti et al. 2005), the contribution of the obligate serpentinophytes to the regional endemic component (*c.* 155 taxa) is proportionally high (7.7%), and comparable to estimates for other ophiolitic systems in temperate regions, e.g. the Balkans (*c.* 6%, Stevanović et al. 2003) and California (*c.* 10%, Kruckeberg 1984). Relatively low species diversity and considerable taxonomic distinctiveness (*c.* 28.7% of obligate endemics plus preferentials) result from the selective pressure of serpentine soils, and are consistent with the insular condition of the ophiolitic outcrops which presumably limits dispersal and biotic homogenization in ecological and evolutionary time (Mac Arthur and Wilson 1967). Hence, regional serpentine habitats fit into the inverse relationship between degree of endemism (high) and floristic richness (low) which is typical of most mediterranean insular systems (Pignatti 1995; Médail and Verlaque 1997). From the structural viewpoint, chamae- and hemicryptophytes are the dominat forms, while the low proportion of short-lived annual plants (therophytes) is apparently in contrast with the xerophile nature of the serpentine flora and the mediterranean location of some of the areas examined. Such a minor role of the Mediterranean component is underscored by the phytogeographical analysis, which highlights a relevant incidence of continental chorotypes, especially the southeastern European element (Arrigoni 1974; Selvi and Bettini 2004).

From the present study it appears that *c*. 24% of the Tuscan serpentine flora is listed in Red Data Books and/or protected by regional laws. The distribution of the 'protected' flora through the five edaphic groups here considered is clearly uneven, with almost half of the taxa being represented by obligate endemics and the other half subdivided in preferentials, facultative and indifferent. This suggests a positive relationship between degree of edaphic fidelity to serpentine soil and vulnerability, and an inverse one between extent of species range and vulnerability. As often happens for naturally rare endemics (Kruckeberg and Rabinowitz 1985), however, most of the obligate serpentinophytes are able to cope with the biological consequences of restricted range and fragmented distribution and do not appear under threat. On the contrary, some of the non-obligate serpentine taxa (e.g. *Allium moschatum*, *Tulipa australis*, *Linum austriacum* ssp. *tommasinii*) have a relevant conservation value because their 'insular' serpentine populations are globally rare and might represent genetically distinct ecotypes which are crucial to safeguard the 'evolutionary fitness' of the species (Falk 1990; Millar and Libby 1991).

At least within the category of the obligate endemics, there seem to be no close relationship between regional frequency and current IUCN category. *Asplenium cuneifolium* and *Armeria denticulata*, for example, are both listed as 'Lower Risk' (Conti et al. 1997) but the low frequency of the former clearly poses it in a more precarious condition than the latter, which occurs in all of the regional serpentine outcrops. This suggests that a meaningful serpentine 'threatspot' analysis can be made only after a re-evaluation of the IUCN categories for both endemics and non-obligate serpentinophytes on the basis of updated data on the distribution and abundance of the populations.

From a conservation viewpoint it is more effective to prioritise the areas based on floristic diversity and number of endemics, as for the traditional 'hotspot' concept (Reid 1998; Médail and Quézel 1999). The present analysis shows that Cecina valley harbours the greatest number of endemics and non-obligate serpentinophytes. Species richness seems connected to the size of the outcrops and to the distance between them, supporting evidence that taxonomic diversity decreases with increasing isolation of the outcrops and with decreasing surface (Harrison et al. 2000). Furthermore, the positive correlation found between floristic and geographic distances is consistent with the finding that patchiness of the serpentine substrate within a given region leads to lower local (within-outcrop) diversity but enhanced among-area diversity (Harrison 1997, 1999). Floristic variation between the areas here examined is in fact considerable; beside a stable group of constant taxa with frequency values between 80 and 100% (which is *c*. 39%), there is a conspicuous component (34%) with a lower frequency and appearing in less than 50% of the areas. Results of Spearman rank correlation analysis suggest that the edaphically indifferent or facultative taxa contribute more than the obligate and preferential serpentinophytes to the higher diversity of the larger outcrops. The lower geographic variation of the obligate serpentinophytes with respect to the other edaphic groups support the 'azonal' character of the 'genuine' serpentine flora, in the sense that it is scarcely dependent on the location and climatic features of the ophiolitic areas.

In order to 'catch' the overall floristic and ecological variation among the regional outcrops, it seems therefore more effective to establish a network of 'Important Plant Areas' (IPAs) rather than to search for a single or few sites with high diversity (Harrison and Inouye 2002). The results of multivariate analyses here presented could be used as a guide for the selection of at least one IPA in each of the five clusters identified, while ordination indicates which taxa should appear in the selected areas. Cecina valley, Monte Ferrato and Murlo in groups no. 1, 2 and 3, respectively, appear as the richest serpentine systems and include most of the taxa accounting for the floristic divergence of the areas, as well as the almost entire set of obligate endemics and preferentials. Including also TIB (group 4) and SAR (group 5), the two more strongly differentiated areas, an 'IPA' network would be obtained which would ensure the conservation of representative aspects of the ecological and geographical components of the Italian serpentine flora.

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