Plant communities in multi-metal contaminated soils: a case study in the National Park of Alta Murgia (Apulia Region - Southern Italy)

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Abstract
A phytosociological study was conducted in the National Park of Alta Murgia in the Apulia region (Southern Italy) to determine the adverse effects of metal contamination of soils on the distribution of plant communities. The phytosociological analyses have shown a remarkable biodiversity of vegetation on non-contaminated soils, while biodiversity appeared strongly reduced on metal-contaminated soils. The area is naturally covered by a wide steppic grassland dominated by *Stipa austroitalica* Martinovský subsp. *austroitalica*. *Brassicaceae* such as *Sinapis arvensis* L. are the dominating species on moderated contaminated soils, whereas spiny species of *Asteraceae* such as *Silybum marianum* (L.) Gaertn. and *Carduus pycnocephalus* L. subsp. *pycnocephalus* are the dominating vegetation on heavily metal-contaminated soils. The presence of these spontaneous species on contaminated soils suggest their potential for restoration of degraded lands by phytostabilization strategy.

Key words: Soil contamination, heavy metals, natural vegetation, phytosociology, phytostabilization.

Introduction

Apulia region is located in the South-East of the Italian peninsula, and is one of the most important agricultural areas of the country. The area under study, the Alta Murgia, is of great naturalistic importance as it is a Natural Park listed among the Sites of European Community Importance (SIC) and the Special Protection Zones (ZPS) in Italy (Italian Ministry for the Environment, Land and Sea, 2007). Even after establishment of the Alta Murgia Natural Park, which contributed to the conservation of the area biodiversity, many problems related to anthropogenic activities in the area remain unsolved (Perrino et al. 2006).

Preliminary investigations (Comune di Altamura 2005; Comune di Gravina 2005) have shown that more than 500 Ha of soils in Alta Murgia contain appreciable amounts of heavy metals (Cr, in particular) originated from inappropriate disposal of various types of wastes. This was mostly due to the lack of control by local authorities, combined with the indifference to safeguard the natural environment by large sectors of the population in the area (Calò and Parise, 2006). In general, relevant information on changes in the natural conditions of an area can be provided by monitoring and studying the vegetation of the area (Teague and Danckwerts, 1989). Most plant species cannot survive on contaminated soils due to toxic effects of heavy metals, and natural landscapes with ecological value can also be destroyed in these areas (Wong, 2003). "Resistance" is a quantitative trait that enables a plant to survive, grow and reproduce in the presence of a particular contaminant (Baker and Walker, 1989). Plant populations can become "resistant" to heavy metals by genetic adaptation or gradual acclimatisation to an increasing heavy metal load (Antonovics et al. 1971; Baker et al., 1986; Dickinson et al., 1991; Punshon and Dickinson 1997).

Recent studies (Brunetti et al., 2009; 2011a,b; 2012; Farrag et al., 2011; Perrino et al., 2009) have shown the interaction of selected vegetal species with heavy metals in the study area. Results of these studies have demonstrated that spontaneous plants growing in the described areas can colonize and survive in soils polluted by multiple metals. Further, results indicated that, most of the plant species are good potential candidates for phytostabilization purposes due to their high metal excluding capacity and their low metal accumulation in above ground parts.

Phytostabilization is a form of phytoremediation that uses plants for long-term stabilization and containment of metal pollutants, and could be associated either to reclamation or maintenance of vegetation in metal contaminated soils. The role of plants is thus to decrease metal mobility in soil by immobilization in the rhizosphere (Cunningham et al., 1995) by plant root exudates. Thus, the ecological conditions that allow the persistence of these plant communities are worth to be studied by considering the delicate equilibria established between natural dynamics and the contaminated regime.

The objectives of this research were to: (1) identify soil metal contamination levels of the studied areas in relation to Italian admissible metal limits; (2) determine which plant species are affected by metal contamination of soil; and (3) establish the relationships between changes in soil contamination and plant communities distribution based on changes of soil properties with respect to vegetation patterns.

Materials and methods

Study areas

The two studied areas are located near the towns of Altamura and Gravina (Fig. 1) in the National Park of Alta Murgia in the Apulia region, South Eastern Italy, which is one of the most important agricultural areas in the country. The Park covers a total surface area of around 70,000 Ha, and includes part of the territories of 13 municipalities. Its altitude is comprised between 300 and 700 metres over the sea level, the climate is of Mediterranean semi-arid type characterized by hot and dry summers and moderately cold and rainy winters, the mean annual precipitation is about 550 mm/y, and the maximum potential evaporation ranges between 5 and 6 mm/day in the month of July.

The Alta Murgia is a calcareous highland with a soil geological substrate mainly consisting of limestones that date back to the cretaceous period (about 130 million years ago). A soil geo-database of the study area is available (Caliandro et al., 2005). The typical Mediterranean vegetation of the area includes natural forests and scrubs, pastures and land cropped by seasonal crops, e.g. winter wheat. Serious alterations of the morphology of wide zones of the area are caused by the practice of "rock-breaking" often applied to turn the original pasture to cropped land. The landscape porosity is greater than that of nearby landscapes (Mininni, 1996).

Site and Soils

Seven and three contaminated sites were investigated, respectively, in the Altamura (A1, A2, A3, A4, A5, A6, A7) and Gravina (G1, G2, G3) areas. An additional waste-disposal spot (G spot) in the Gravina area, where the natural vegetation disappeared probably due to the toxic effect of the high quantity of disposed waste, was also investigated (Fig. 2). For comparison, five non-contaminated sites in Altamura (AB, AB1, AB3, AB4, AB5) and nine in Gravina (GB, GB1, GB2, GB3, GB4, GB5, GB6, GB7, GB8) areas were studied. The surface area of these sites varied depending on a variety of factors including the quantity and type of disposed waste, topographic conditions, etc. Except the waste spot (G spot), about one hectare for each polluted site was investigated.

The sites investigated are characterized by shallow (<25 cm depth) Typic Haploxeralfs, fine-loamy, mixed, thermic soils (Soil Taxonomy, 2003). Ten soil subsamples were collected in different directions in each site using a hand auger. The subsamples of each site were then mixed to obtain a composited sample, and transported to the laboratory, air-dried, crushed and passed through a 2-mm sieve.

The total content of heavy metals (Cd, Cr, Cu, Ni, Pb and Zn), were measured by inductively coupled plasma optical emission spectrometry (ICP-OES, ICAP 6300 Thermo Electron) on composite soil sample extracts obtained by microwave-assisted digestion with a suprapure HNO_3: H_2O_2: HCl mixture (5:1:1 v/v). Further details on the physical and chemical properties of studied soils and their metal bioavailability can be found in previous publications (Farrag et al., 2011; Brunetti et al., 2009).

Plant communities

A survey of n. 24 vegetation units "reléve" was conducted throughout the studied sites, at different elevation, exposure and slope, following the phytosociological method of the Zurich-Montpellier school (Braun-Blanquet, 1932). The analysis was conducted with the support of Flora d'Italia (Pignatti, 1982), Flora Europea (Tutin et al., 1968-1976) and Orchidacee d'Italia (Grünanger, 2000). Unless otherwise indicated, the nomenclature was standardized using the checklist of the Italian Flora (Conti et al., 2005; 2007). A synopsys of the vegetation units is presented in Table 2 and 3.

The GPS (Global Positioning System) locations expressed in UTM (Universal Transverse Mercator) coordinates, the codes (date and "reléve" numbers), and the points and locations are listed in Appendix 1.

Statistical analysis

The phytosociological data, based on a total of 24 reléves, were classified by cluster analysis using presence/absence value (option for clustering: complete link; resemblance coefficient: Jaccard). The average and range (minimum, maximum) contents of each heavy metal in soil were calculated considering the vegetal species as independent variables. The distribution of the plant communities according to the pollution of the studied sites was represented by dispersion graphics reporting the contents of the most concerned metals (Cr, Cu, Pb, Zn). All statistical analyses were performed using the Statgraphics 5.1 software.

Results and discussion

Metal contamination of soils

The total contents (mg kg^{-1}, d.w.) of Cr, Pb and Zn in all contaminated sites exceeded the maximum allowable limits imposed by the Italian law (Ministry of Environment, 2006) in soils in public and private green areas and for residential uses (Table 1). The Cu concentration was slightly lower than the maximum permitted value only in soils A5 and G2, while Cd concentration in soil G3 was slightly higher than the admissible value (Table 1).

Based on the total content of studied metals, the contamination level of the sites studied followed the order: G spot > A6 > A4 > A2 > A3 > G3 > A7 > A1 > A5 > G1 > G2, whereas the levels of metal contents were in the order: Cr > Zn > Pb > Cu > Cd.

Plant communities composition

The phytosociological analysis of the vegetation conducted in the 24 reléves indicated the existence of 4 classes, which are suddivided into five orders, five alliances, two associations, one subassociation and three aggregations (Table 1, 2, 3; Figs 3, 4, 5, 6, 7). The cluster analysis could separate two major clusters, A and B (Fig. 8). In cluster A, which included plant communities adapted to a high contamination level, two main groups were identified, A1 and A2. The group A1 included *Legousio hybridae-Biforetum testiculatae* association (Table 2; reléves 9-14), while the group A2 included *Onopordion illyrici* alliance (Table 2; reléves 1-8). In cluster B, which included the plant communities adapted to a low contamination level, two main groups were identified, B1 and B2. The group B1 included the coenosis, in particular the *Crepis* sp. pl. group (Table 2; reléves 15-18), while cluster B2 included perennial grassland. In the perennial grassland group, clusters B2.2 (Agg. to *A. ramosus*) and B2.1 (*Acino suaveolentis-Stipetum austroitalicae*) belong to thermoxerophilous and mesophilous, respectively. In conclusion, the following syntaxonomic scheme is proposed for the studied areas:

ARTEMISIETEA VULGARIS Lohmeyer, Preising & Tüxen ex von Rochow 1951
ONOPORDENEA ACANTHII Rivas-Martínez, Báscones, T.E. Díaz, Fernadéz-Gonzáles & Loidi 2002
CARTHAMETALIA LANATI Brullo in Brullo & Marcerò 1985
Onopordion illyrici Oberdorfer 1954
Silybum marianum and *Carduus pycnocephalus* subsp. *pycnocephalus* communities

LYGEO-STIPETEA Rivas-Martínez 1978
HYPARRHENIETALIA Rivas-Martínez 1978
Hyparrhenion hirtae Br.-Bl., P. Silva & Rozeira 1956
Asphodelus ramosus communities

FESTUCO-BROMETEA Br.-Bl. & Tüxen ex Klika & Hadač 1944
SCORZONERO-CHRYSOPOGONETALIA Horvatić & Horvat (1956) 1958
Hippocrepido glaucae-Stipion austroitalicae Forte, Perrino & Terzi 2005
Acino suaveolentis-Stipetum austroitalicae Forte, Perrino & Terzi 2005
stipetosum austroitalicae Forte, Perrino & Terzi 2005

STELLARIETEA MEDIAE Tüxen, Lohmeyer & Preising ex von Rochow 1951
STELLARIENEA MEDIAE Huppe & Hofmeister, ex Theurillat, in Theurillat, Aeschimann, Küpfer et Spichiger, 1995
CENTAUREETALIA CYANI Tüxen ex von Rochow 1951
Roemerion hybridae Br.-Bl. ex Rivas-Martínez, Fernández-Gonzáles & Loidi 1999
Legousio hybridae-Biforetum testiculatae Di Martino & Raimondo 1976
CHENOPODIO-STELLARIENEA Rivas Goday 1956
THERO-BROMETALIA (Rivas Goday & Rivas-Martínez ex esteve 1973) O. Bolòs 1975
Echio plantaginei-Galactition tomentosae O. Bolòs & Molinier 1969
Crepis sp. pl. communities

Soil contamination and vegetation distribution

In general, the results of the 24 phytosociological reléves (Table 2) indicated the existence of four phytosociological classes expressing different ecological conditions. In the moderate polluted areas, the class of *Stellarietea mediae* Tüxen, Lohmeyer & Preising ex von Rochow 1951 was dominating and represented by two vegetation types.

The physiognomic features of the first one are directly linked to the dominance of *S. arvensis* that recognized the association of *Legousio hybridae-Biforetum testiculatae* Di Martino & Raimondo 1976. The associations indicated by this syntaxonomic unit are composed of infestant species that can colonise the seasonal crops (e.g. winter wheat).

The second vegetation type included associations that can be found in contexts affected by human activities, in particular where rock-breaking was practiced. Typical examples are represented by the plant communities rich in species of the genus *Crepis* L., such as *C. vesicaria* L., *C. corymbosa* Ten. and *C. rubra* L.

In the slightly and/or non polluted areas, two coenoses distinct herbaceous plants were observed (Table 2), the perennial mesophilous grass *Festuco-Brometea* Br.-Bl. & Tüxen ex Klika & Hadač 1944 and the thermoxerophilous grass *Lygeo-Stipetea* Rivas-Martínez 1978. Because of their great naturalistic and ecological importance, these two kinds of vegetation are included as priority habitats in Annex II of Directive 92/43 EEC (European Commission DG Environment, 2007; Biondi and Blasi, 2009).

The association of *Acino suaveolentis-Stipetum austroitalicae*, aggregations to *Asphodelus* and to *Crepis* (Table 3, Fig. 9) were found on soils with metal contents generally below the lower value of ranges, and where the maximum metal contents (Cr 620.7, Cu 138.3, Pb 170.3, Zn 383.7, mg kg^{-1}) were lower than the average values measured in the sites studied. In particular, the *Acino suaveolentis-Stipetum austroitalicae* community grew on soils with the lowest contents of metals (Cd 0.37, Cr 30.3, Cu 9.5, Ni 28.2, Pb 56.2, mg kg^{-1}) except Zn (Table 3, Fig. 9), and the aggregations to *Crepis* on soils where the contents of some metals (Cr 103.1, Cu 103.5, Pb 91.2, Zn 106.6, mg kg^{-1}) were similar to the limits established by the Italian law and those of Ni and Pb were below (Table 3, Fig. 9). Only the *Legousio hybridae-Biforetum testiculatae* and *Onopordion illyrici* (or no vegetation) syntaxa were found frequently on soils where metals contents were above these limits. In particular, the *Onopordion illyrici* alliance was able to grow on soils with metal contents (Cd 2.48, Cr 2488.1, Cu 902.3, Ni 109.2, Pb 890.8, mg kg^{-1}), except Zn, which were much higher than the upper limits usually considered to adversely affect plant growth (Kabata-Pendias and Pendias, 1984).

Restoration potential of plant communities

The capacity of the plant communities studied to grow on contaminated soils represents a valuable means for the restoration of degraded lands by the phytostabilization strategy. The methods of intervention should include two phases.

The first phase consists in the removal or reduction of the harmful metal contaminants through phytoremediation techniques. Preliminary studies (Brunetti et al., 2009; 2011a,b; 2012; Farrag et al., 2011; Perrino et al., 2009) have demonstrated that spontaneous plant species, such as *Carduus pycnocephalus* L. subsp. *pycnocephalus*, *Dasypyrum villosum* (L.) P. Candargy, *Ferula communis* L., *Silybum marianum* (L.) Gaertner, *Sinapis arvensis*, and *S. austroitalica* subsp. *austroitalica*, which grow naturally in the areas studied, are able to colonize and survive on soils characterized by multiple metal pollution. The studied plants are indigenous species well adapted to the climatic environment and to adverse water and nutritional conditions, so they are ideal plants for establishing an overall and self-sustainable vegetation cover in these sites. Where the high metal concentrations and/or adverse soil properties are limiting factors, phytostabilization techniques would most likely be used (Brunetti et al., 2009; Farrag et al., 2011).

The second phase includes *in situ* conservation and recovery strategies for the priority habitat "Pseudo-steppe" with grasses and annuals of the "*Thero-Brachypodietea*" (Annex II - Dir 92/43/EEC Habitat). The methods, techniques and timing for the *in situ* conservation of these species and their habitat should include the collection of plant material on site and their reintroduction in the areas.

Conclusions

In this work changes of the plant communities were studied in relation to soil contamination in order to possibly establish the trends of soil changes based on the observation of vegetation patterns. With this aim, the effects of soil contamination by heavy metals on vegetation biodiversity were monitored in the National Park of Alta Murgia (southern Italy). Results obtained revealed that the study of vegetation associations may have great value in the Alta Murgia ecosystem. Considerable differences were found among plant communities in their capacity to grow on heavy metals contaminated soil (Fig. 10). According to the species occurrence found along the contamination gradient, *S. marianum* and *C. pycnocephalus* subsp. *pycnocephalus* appeared to be more resistant than *S. arvensis* and *F. communis*, whereas *S. austroitalica* subsp. *austroitalica* was the most sensitive *taxon*. The spread of these plant communities in these contaminated areas appeared to produce an effective plant cover on the long term. Generally, the presence of these spontaneous species should be taken into due account in order to plan future remediation strategies by the use of phytostabilization techniques.

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Table 1. Vegetation type and total contents of heavy metal levels in soils studied and maximum levels (mg kg^{-1}, d.w.) in soils admitted by the Italian Law.

Vegetation type	Locations	Total(a) contents of heavy metal (mg kg^{-1}, d.w.)					
		Cd	Cr	Cu	Ni	Pb	Zn
Altamura							
Onopordion illyrici	A1	1.4 (0.7)	939.7 (6.3)	152.4 (1.3)	60.6 (0.5)	179.6 (1.8)	682.8 (4.6)
Onopordion illyrici	A2	1.47 (0.7)	1,738.5 (11.6)	334.1 (2.8)	72.5 (0.6)	230.8 (2.3)	896.7 (6.0)
Onopordion illyrici	A3	1.45 (0.7)	1,385.9 (9.2)	169.9 (1.4)	80.1 (0.7)	890.8 (8.9)	407.8 (2.7)
Onopordion illyrici	A4	1.57 (0.8)	1,770.4 (11.8)	296 (2.5)	89.2 (0.7)	292.2 (2.9)	1,149.9 (7.7)
Legousio hybridae-Biforetum testiculatae	A5	1.72 (0.9)	999.6 (6.7)	115 (1.0)	72.3 (0.6)	137.2 (1.4)	482.2 (3.2)
Onopordion illyrici	A6	1.67 (0.8)	2,488.1 (16.6)	187.7 (1.6)	109.2 (0.9)	208.2 (2.1)	921.5 (6.1)
Legousio hybridae-Biforetum testiculatae	A7	1.53 (0.8)	1,137.5 (7.6)	153.6 (1.3)	69.6 (0.6)	176.8 (1.8)	739.3 (4.9)
Legousio hybridae-Biforetum testiculatae	AB	1.2 (0.6)	45.0 (0.3)	22.5 (0.2)	37.5 (0.3)	75.1 (0.8)	120.1 (0.8)
Legousio hybridae-Biforetum testiculatae	AB1	1.3 (0.7)	53.4 (0.4)	22.9 (0.2)	30.5 (0.3)	76.2 (0.8)	99.0 (0.7)
Acino suaveolentis-Stipetum austroitalicae	AB3	*0.57 (0.3)*	*42.3 (0.3)*	*9.5 (0.1)*	*28.2 (0.3)*	*56.2 (0.6)*	74.2 (0.6)
Aggr. to *Crepis* sp. pl.	AB4	1.1 (0.6)	43.2 (0.3)	19.7 (0.2)	31.3 (0.3)	74.7 (0.8)	97.6 (0.7)
Aggr. to *Asphodelus ramosus*	AB5	0.92 (0.5)	43.1 (0.3)	17.8(0.2)	29.3 (0.3)	66.7 (0.7)	*73.1 (0.6)*
Gravina in Puglia							
Onopordion illyrici	G1	0.58 (0.3)	816.6 (5.4)	134.6 (1.1)	31.1 (0.3)	183.1 (1.8)	521.8 (3.5)
Onopordion illyrici	G2	0.45 (0.2)	459.3 (3.1)	104.2 (0.9)	46.8 (0.4)	193.5 (1.9)	474.2 (3.2)
Onopordion illyrici	G3	2.48 (1.2)	856 (5.7)	902.3 (7.5)	36.3 (0.3)	221.6 (2.2)	604.2 (4.0)
without vegetation cover	G spot	1.83 (0.9)	2,039.1 (13.6)	368.3 (3.1)	55.6 (0.5)	470 (4.7)	1,373.5 (9.2)
Legousio hybridae-Biforetum testiculatae	GB	1.53 (0.8)	107.9 (0.7)	30.4 (0.3)	39.7 (0.3)	90.8 (0.9)	99.9 (0.7)
Legousio hybridae-Biforetum testiculatae	GB1	1.48 (0.7)	127.2 (0.8)	30.9 (0.3)	36.1 (0.3)	74.8 (0.7)	100.2 (0.7)
Acino suaveolentis-Stipetum austroitalicae	GB2	*0.37 (0.2)*	*30.3 (0.2)*	19.4 (0.2)	36.8 (0.3)	*71.2 (0.8)*	*80.3 (0.6)*
Aggr. to *Asphodelus ramosus*	GB3	0.89 (0.5)	44.0 (0.3)	21.5 (0.2)	34.9 (0.3)	72.6 (0.8)	95.1 (0.7)
Aggr. to *Asphodelus ramosus*	GB4	0.57 (0.3)	39.8 (0.3)	*10.1 (0.1)*	*33.6 (0.3)*	77.5 (0.8)	94.8 (0.7)
Aggr. to *Asphodelus ramosus*	GB5	0.56 (0.3)	55.7 (0.4)	101.3 (0.9)	63.2 (0.6)	92.1.(0.9)	103.2 (0.7)
Aggr. to *Crepis* sp. pl.	GB6	1.05 (0.5)	103.1 (0.7)	103.5 (0.9)	74.1 (0.6)	74.7 (0.8)	95.6 (0.7)
Aggr. to *Crepis* sp. pl.	GB7	0.91 (0.5)	53.8 (0.4)	99.7 (0.9)	45.3 (0.4)	80.1.(0.8)	106.6 (0.7)
Aggr. to *Crepis* sp. pl.	GB8	1.46 (0.7)	99.8 (0.7)	31.2(o.3)	37.7 (0.3)	91.2 (0.9)	100.9 (0.7)
The Italian Limits(b)		2	150	120	120	100	150

(a) In parentheses are the ratio soil content/Italian limit (value >1 means action required).
(b) Maximum total metal contents in soils for public and private green areas and residential sites allowed by the Italian Law (Ministry of Environment 2006).

Table 2. Synoptic table of the vegetation units studied

Relevè number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Town code	A	A	A	A	A	G	G	G	A	A	A	A	G	G
Spot code	A1	A2	A3	A4	A6	G1	G2	G3	AB	AB1	A5	A7	GB	GB1
Altitude (m a. s.)	510	523	527	527	515	626	626	631	503	526	512	535	637	630
Aspect	-	-	-	-	NE	-	-	-	-	-	-	NE	-	SW
Slope (°)	3	2	0	0	3	0	2	0	0	0	0	2	0	2
Relevè area (m^2)	25	25	40	60	35	20	30	40	50	30	40	20	40	50
Stoniness (%)	10	20	30	10	5	5	5	15	15	50	10	10	40	50
Rockiness (%)	5	10	5	0	0	0	5	10	5	0	5	0	5	5
Cover total (%)	100	90	70	95	95	100	100	90	75	50	80	100	60	70
Average height of herb layer (cm)	60	50	30	40	70	60	60	50	30	25	40	90	50	25
Number of species	9	17	17	22	20	9	9	10	-	-	-	-	-	-
Charact. species of All. (*ONOPORDION ILLYRICI*) and Ord. (*CARTHAMETALIA LANATI*)														
Silybum marianum (L.) Gaertner	5	3	1	3	2	5	5	3	.	.	+	1	.	+
Onopordum illyricum L.	+	.	+	+	+	.	.	.	.	.	.	.	.	.
Cynara cardunculus L. subsp. *cardunculus*	.	+	+	.	.	1	+	.	.	.	.	.	+	.
Scolymus hispanicus L.	.	.	.	+	+	.	.	.	.	.	.	.	.	.
Charact. species of Association (*LEGOUSIO HYBRIDAE-BIFORETUM TESTICULTAE*)														
Legousia hybrida (L.) Delarbre									+	+	+	.	+	1
Charact. species of Cl. (*ARTEMISIETEA VULGARIS*)														
Carduus pycnocephalus L. subsp. *pycnocephalus*	+	1	3	1	4	.	+	.	.	.	+	+	.	1
Picris hieracioides L.	+	.	.	.	.	+	.	+	.	.	.	.	.	.
Galactites elegans (All.) Soldano	.	.	.	.	+	1	.	+	.	.	+	.	.	.
Carduus nutans L. subsp. *macrocephalus* (Desf.) Nyman	.	.	+	+	.	.	.	.	.	.	.	.	.	.
Cichorium intybus L.	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Cynoglossum cheirifolium L. subsp. *cheirifolium*	.	+	.	.	.	.	.	.	.	.	.	.	.	.
Charact. species of All. (*ROEMERION HYBRIDAE*), Ord. (*CENTAUREETALIA CYANII*) and Cl. (*STELLARIETEA MEDIA* E)														
Sinapis arvensis L.	+	2	+	1	+	1	+	+	2	1	2	5	3	4
Papaver rhoeas L. ssp. *rhoeas*	.	.	.	.	.	1	+	+	2	1	+	+	+	2
Scandix pecten-veneris L.	.	.	.	.	.	.	.	.	+	1	1	.	1	.
Muscari comosum (L.) Mill.	.	.	.	.	.	.	.	.	+	+	+	+	+	+
Bifora testiculata (L.) Spreng.	.	.	.	.	.	.	.	.	+	1	+	+	.	+
Gladiolus italicus Miller	.	.	.	.	.	.	.	.	1	+	1	+	+	.
Avena barbata Pott. ex Link	.	.	.	+	+	.	.	.	+	1	+	+	.	+
Fumaria officinalis L.	+	+	.	.	+	+	1	+	+	.	+	.	.	1
Sonchus oleraceus L.	.	.	.	1	+	.	.	.	+	.	.	+	+	+
Nigella damascena L.	.	.	.	.	.	.	.	.	.	+	.	1	.	+
Sherardia arvensis L.	.	.	.	.	.	.	.	.	+	1	.	.	+	.
Filago pyramidata L.	.	.	.	.	.	.	.	.	.	+	+	+	.	.
Dasypyrum villosum (L.) P. Candargy	+	.	.	1	+	1	+	1	.	.	1	+	3	1
Stellaria media (L.) Vill. subsp. *media*	.	1	+	+	.	.	.	.	+	.	.	.	+	.
Anagallis arvensis L.	.	.	.	+	.	.	.	.	.	.	+	+	+	.
Calendula arvensis L.	.	.	.	.	.	.	.	.	.	.	+	.	+	.
Bromus diandrus Roth. subsp. *maximus* (Desf) Soó	.	.	.	.	.	.	.	.	.	.	.	2	.	2
Adonis annua L.	.	.	.	.	.	.	.	.	+	+	.	.	.	.
Cardamine hirsuta L.	.	.	.	.	.	.	.	.	+		+	+		
Vicia sativa L. subsp. *nigra* (L.) Ehrh.	.	.	.	.	.	.	.	.	.	.	.	.	+	.
Euphorbia helioscopia L. subsp. *helioscopia*	+	+	.	+	.	.	.	+	.	.	.	.	1	+
Lolium rigidum Gaudin subsp. *lepturoides* (Boiss.) Sennen & Mauricio	.	.	.	.	.	.	.	.	+	+	.	.	.	.
Bromus hordeaceus L.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Legousia falcata (Ten.) Janch.	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Coronilla scorpioides (L.) W.D.J. Koch	.	.	.	.	.	.	.	.	.	.	.	1	+	.
Lepidium draba (L.) Desv. ssp. *draba*	.	.	.	.	+	.	.	.	.	.	.	.	.	.
Capsella bursa-pastoris (L.) Medik. ssp. *bursa-pastoris*	+	1	1	.	+	.	.	.	.	.	.	.	.	+
Thlaspi arvense L.	.	.	.	.	.	.	.	.	.	+	.	.	.	.
Crepis sancta (L.) Babc. ssp. *sancta*	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Galactites elegans (All.) Soldano	.	.	.	.	.	.	.	.	.	.	+	.	.	.
Echium plantagineum L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sulla capitata (Desf.) B.H. Choi & H. Ohashi	.	.	.	.	.	.	.	.	.	.	.	.	1	.
Bartsia trixago L.	.	.	.	.	.	.	.	.	.	.	.	.	.	+
Raphanus raphanistrum L.	.	.	.	.	.	.	.	.	.	.	.	.	.	+

Table 3. Synoptic table of the vegetation units studied

Relevè number	15	16	17	18	19	20	21	22	23	24
Town code	A	G	G	G	A	G	G	G	A	G
Spot code	AB4	GB6	GB7	GB8	AB5	GB3	GB4	GB5	AB3	GB2
Altitude (m a. s.)	502	631	637	630	523	620	627	625	520	630
Aspect	-	SW	-	NW	NE	NW	-	-	-	NW
Slope (°)	2	3	0	0	2	2	0	4	2	0
Relevè area (m^2)	80	60	60	20	50	60	40	30	150	100
Stoniness (%)	80	60	50	30	10	20	20	20	10	12
Rockiness (%)	5	5	0	0	5	0	10	15	20	20
Cover total (%)	80	70	70	70	80	90	70	85	100	100
Average height of herb layer (cm)	40	30	30	40	60	45	30	70	60	50
Number of species	41	46	48	48	55	38	32	32	63	61
Charact. and differential species of aggr.										
Crepis vesicaria L. ssp. *vesicaraia*	2	5	5	5	+	.	.	+	.	.
Crepis corymbosa Ten.	3	+	1	.	+	.	.	.	+	+
Crepis rubra L.	1	1	+	1	+	.	.	.	.	.
Aggr.										
Asphodelus ramosus L. subsp. *ramosus*	.	.	+	.	4	2	3	2	.	.
Charact. species of Association (*ACINO SUAVEOLENTIS-STIPETUM AUSTROITALICAE stipetosum austroitalicae*)										
Potentilla detommasii Ten.	.	.	.	.	+	+	.	.	1	+
Carduus micropterus (Borbás) Teyber subsp. *perspinosus* (Fiori) Kazmi	.	.	.	.	.	.	.	.	+	1
Euphorbia nicaeensis All. subsp. *japygica* (Ten.) Arcang.	.	.	.	.	+	.	.	.	+	.
Thymus spinulosus Ten.	.	.	.	.	.	.	.	.	.	+
Charact. species of All. (*ECHIO PLANTAGINEI-GALACTITION TOMENTOSAE*)										
Hypochaeris achyrophorus L.	+	1	+	+	.	.	.	.	.	+
Echium plantagineum L.	.	+	+	+	+	+	.	.	.	.
Tordylium apulum L.	.	+	+	+	+	+	.	.	.	.
Galactites elegans (All.) Soldano	.	.	+	.	.	.	.	.	.	.
Charact. species of Ord. (*THERO-BROMETALIA*)										
Avena barbata Pott. ex Link	+	1	+	1	+	+	.	.	+	1
Dasypyrum villosum (L.) P. Candargy	1	+	1	+	.	1	.	2	+	+
Trifolium stellatum L.	1	1	+	+	+	.	.	.	+	+
Catapodium rigidum (L.) C. E. Hubb. ex Dony	+	+	.	.	.	.	.	.	+	.
Medicago orbicularis (L.) Bartal.	+	+	.	.	.	.	.	.	.	.
Medicago truncatula Gaertner	+	.	+	.	.	.	.	.	.	.
Astragalus hamosus L.	.	+	+		.	.	.	.	.	.
Hirschfeldia incana (L.) Lagr.-Foss. subsp. *incana*	.	+	+	.	.	.	.	.	.	.
Vulpia ciliata Dumort.	.	1	.	+	.	.	.	.	+	.
Triticum ovatum (L.) Raspail	+	.	.	.	.	.	.	.	+	+
Bromus hordeaceus L.	.	.	.	+	.	.	.	.	+	.
Bromus diandrus Roth. subsp. *maximus* (Desf) Soó	.	.	.	+	.	.	.	.	.	.
Charact. species of Cl. (*STELLARIETEA MEDIAE* and *CHENOPODIO-STELLARIENEA*)										
Anagallis arvensis L.	+	1	+	+	+	+	+	.	+	+
Filago pyramidata L.	+	+	+	+	+	.	.	.	+	+
Sonchus oleraceus L.	+	+	+	+	.	1	.	+	.	.
Linum strictum L. subsp. *strictum*	+	1	.	+	1	.	.	.	2	1
Euphorbia exigua L. subsp. *exigua*	+	+	+	.	+	+	.	.	+	+
Malva sylvestris L. subsp. *sylvestris*	+	+	+	.	.	.	.	.	.	.
Capsella bursa-pastoris (L.) Medik. ssp. *bursa-pastoris*	+	.	+	+	.	.	.	.	.	.
Anthemis arvensis L.	.	+	+	+	.	+	.	.	.	.
Coronilla scorpioides (L.) W.D.J. Kock	.	+	+	+	+	1	.	.	.	.
Vicia sativa L. subsp. *nigra* (L.) Ehrh.	.	+	+	+	.	.	.	.	.	.
Sherardia arvensis L.	.	+	+	.	1	+	+	1	+	+
Euphorbia helioscopia L. subsp. *helioscopia*	.	+	.	+	.	+	.	.	.	.
Sideritis romana L. subsp. *romana*	+	.	.	.	.	.	.	.	.	+
Lathyrus ochrus (L.) DC.	.	+	.	.	.	.	.	.	.	.
Bartsia trixago L.	.	.	.	+	.	.	.	.	+	+
Lepidium draba (L.) Desv. subsp. *draba*	.	.	.	+	.	.	.	.	.	.
Senecio leucanthemifolius Poir. subsp. *leucanthemifolius*					+	.	1	.		
Adonis annua L.					+	.	.	1		

Legends for figures

Fig. 1. Geographical location of the study area.
Fig. 2. Absence of vegetation in the G spot (Gravina area).
Fig. 3. Vegetation of *Silybum marianum* and *Carduus pycnocephalus* subsp. *pycnocephalus* (Gravina area).
Fig. 4. Boundary between *Onopordion illyrici* (A) and *Crepis* sp. pl. communities group (B) (Gravina area)
Fig. 5. Vegetation of *Sinapis arvensis* (Altamura area).
Fig. 6. Annual meadows and the formation of *Silybum marianum* (Gravina area).
Fig. 7. Mesophilous perennial grasslands of *Acinos suaveolentis-Stipetum austroitalicae* (Altamura area).
Fig. 8. Dendrogram of the phytosociological relèves.
Fig. 9. Distribution of plant communities the vegetal species according to contents of heavy metals (mg kg-1, dw).
Fig. 10. Correspondence between the gradient of concentration of heavy metals and type of vegetation.