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Assessment of soil quality in wetlands in Eastern Sicily

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ABSTRACT

Wetlands are of great importance for biodiversity as they support a rich variety of plant and animal species, and the presence of endemic and migratory species is frequent. It is therefore necessary to protect and monitor such areas. The work conducted, reported in the present paper, aimed to verify the quality of soil in most wetlands in eastern Sicily. Specifically, four areas were studied: three Oriented Nature Reserves (RNO), the Saline di Priolo, with the adjacent Penisola di Magnisi, the Saline di Siracusa, and the Faunistic Oasis of Vendicari[1], and one Special Protection Area (SPA), the Biviere di Lentini. The study areas were sampled in 12 different sites, in spring and in autumn, to monitor soil fauna and assess the soil biological quality through the calculation of the QBS-ar. The results represent the first data relating to the QBS-ar in Sicily and, in particular, relating to wetlands.

The QBS-ar values recorded were all higher, for both seasons, than the averages reported for land use by Menta et al., 2018. The statistical analysis regarding annual QBS-ar divides the sites into two groups: Saline di Priolo1, Marianelli1, Cittadella1, Vendicari1, Biviere di Lentini2 with a QBS-ar > 200 and Biviere di Lentini1, Saline di Priolo2, Penisola di Magnisi1, Penisola di Magnisi2, Saline di Siracusa1 and Saline di Siracusa2 with QBS-ar < 200; Calamosche1 site show no significant difference between the two groups. Although the number of individuals varied considerably in the two seasons, there are no seasonal differences in the number of taxa and in the QBS-ar.

The chemical-physical parameters that influenced the fauna composition and the QBS-ar were mostly those related to the soil texture; some groups were positively correlated with the percentage of silt, while others were negatively correlated with the percentage of sand. The QBS-ar show the same correlations with silt and sand. Proximity or non-proximity to water did not determine variations in the fauna composition and in the QBS-ar values. Soil salinity appeared to be a factor influencing the fauna composition, but further studies are needed to confirm such relief.

1. Introduction

Proper functioning of an ecosystem depends on variety and variability of living organisms in the planet's ecosystems, which constitutes a fundamental resource for humans (Lawton & Jones, 1995; Jones et al., 1994; Luck, et al., 2009). Each species interacts differently with the ecosystem, contributing to soil formation and evolution, and to transformation of nutrients (Scheu & Schulz, 1996; Wolters, 2000); the reduction in biodiversity causes an alteration in the evolutionary processes of soil formation (Chapin Iii et al., 2000; Nielsen et al., 2015; Targulian, & Krasilnikov, 2007). Soil invertebrates contribute to ecological succession, decomposition and transformation of organic matter, carbon, nitrogen, phosphorus, sulphur and water cycles, the release of elements available to plants and other organisms, control of the water regime, mitigation of chemical and biological contamination, and preservation of the genetic heritage (Brussaard, 1997; Fitter et al., 2005; Lavelle et al., 2006; Lebrun, 1987; Reichle, 1977). Arthropod fauna provides one of the most important influences on the ecology of wetlands and have great biodiversity in these environments (Batzer & Wu, 2020).

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[1] The Oasis takes the overall name of Vendicari, in reality it is made up of various localities that take on different names: Vendicari, Marianelli, Cittadella, Calamosche.

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Bioindicators for assessing sustainability of land use have been the main focus of various types of research in recent decades (Paoletti, 2012). Several studies focused on monitoring the biological quality of soil, more specifically through the use of QBS-ar index (QBS-ar - Soil Biological Quality of Microarthropods) (Madej et al, 2011; Galli et al., 2014; Menta et al., 2018; Parisi et al., 2005). This index is based on the principle of the presence/absence of biological forms of edaphic microarthropods (Parisi et al., 2005). It combines the biodiversity (in terms of class and orders) of soil microarthropod community with the degree of vulnerability of soil animals and provides information on soil biological quality (Menta et al., 2018). To each biological form is assigned a numerical value, an eco-morphological index (EMI) ranging from 1 to 20, relating to the degree of adaptation to the soil and the nature of the land; the sum of the EMI values determines the QBS-ar. As it can be seen from the literature of recent years, numerous studies have been carried out relating the QBS-ar value to different types of land use, more specifically Menta et al. (2018) identified eight groupings in relation to land use: 1) Agricultural land (A, various crops, arable and non-crop, organic, conventional), 2) Woodland (W, forest, scrub and bush), 3) Restored (R, vegetated reclamation, restored mine, *peri*-urban fallow), 4) Natural degradation (ND, soils in natural degraded condition, e.g. serpentine soils, soils in Brûlés), 5) Permanent grasslands, pastures and meadows (G), 6) Orchards (O), 7) Urban parks, urban residual forests, public gardens, botanical gardens, home gardens (UP), 8) Soils involved in anthropogenic degradation (D). No specific mention is made of wetlands.

Wetlands are of great importance for biodiversity (e.g., Denny, 1994). They host a rich variety of plant and animal species, with the frequent presence of endemic and migratory species, but they are increasingly subjected to environmental stress that makes them even more sensitive to the impact of climate change. For this reason, most wetlands are protected areas. Wetlands offer a range of habitats for terrestrial arthropods, with unique faunas being associated with soils and ground litter, living-plant substrates, and peatlands (Batzer & Wu, 2020).

In eastern Sicily there are numerous wetlands that have acquired the status of Reserve over time. However, these areas are in different situations both in terms of protection, of size and for different anthropic impacting factors.

Object of the present research were four areas in the province of Syracuse: three Oriented Nature Reserves (RNO), the Saline di Priolo, with the adjacent Penisola di Magnisi, the Saline di Siracusa, and the Faunistic Oasis of Vendicari[1], and one Special Protection Area (SPA), the Biviere di Lentini.

The aims of this study were to:

- o assess the soil quality of the above mentioned wetlands through the use of QBS-ar index and the composition of microarthropod community in terms of number of individuals and number of taxa. This in order to know soils current status of the sampled areas and to build a pilot-study for future monitoring programs;
- o evaluate if proximity of water basins influences the fauna composition;
- o verify possible correlations between fauna and chemical-physical parameters of soil;
- o confirm the effectiveness of QBS-ar also in these environments, as now widely demonstrated for other natural biotopes.

2. Materials and methods

2.1. Study areas

The areas studied are all protected wetlands (Oasis, natural reserves) in the territory of Syracuse (Sicily, Italy). The 4 areas were sampled in 12 different sites: Saline di Priolo1 (SP1), Saline di Priolo2 (SP2), Penisola di Magnisi1 (PM1) Penisola di Magnisi2 (PM2), Vendicari (VE1), Marianelli (MA1), Cittadella (CI1), Calamosche (CA1), Biviere di Lentini1 (BL1), Biviere di Lentini2 (BL2), Saline di Siracusa1 (SS1), Saline di Siracusa2 (SS2). They all represent an ideal habitat for a multitude of plants, birds and fishes, and are essential areas for resting and nesting for various bird species.

They are all coastal wetlands except Biviere di Lentini which is located 13 km as the crow flies from the sea. In Table 1 the data collected on field of the sampled locations.

Some of the samplings were carried out closer to the wetlands (SP1, SP2, VE1, CI1, BL1, BL2, SS1, SS2) and others further away (PM1, PM2, MA1, CA1) to verify the possible influence on the fauna of the proximity of water. In Fig. 1 the map with the sampling sites.

The RNO of Vendicari is the oldest wetland reserve (established in 1984) and the largest. The Penisola di Magnisi and the site SS1 are among the most anthropized areas due grazing for Magnisi and waste materials in SS1. The SS2 site is the closest to the sea and is the only one affected by tidal phenomena and saline deposits.

Some of the sampled sites fall into the categories established by Menta et al. (2018) with respect to land use: SP1 and SP2 class R; PM1 PM2 class G; (VE1), (MA1), (CI1) and (CA1) class W; BL2 class A. BL1, SS1, SS2 due to their particular land use cannot be included in any of the categories.

Table 1
Sampled locations data collected on field.

Samplig site	Acronym	GPS coordinates	Distance from water body	Vegetation
Biviere di Lentini 1	BL1	N.: 37.32932922° E.: 14.9290737°	5 *m*	Riparian vegetation (*Tamarix*)
Biviere di Lentini 2	BL2	N.: 37.329859° E.: 14.929672°	86 *m*	Cultivated land (*Hedysarum coronarium*)
Penisola di Magnisi 1	PM1	N.: 37.157975° E.: 15.23187582°	1370 *m*	Steppe vegetation
Penisola di Magnisi 2	PM2	N.: 37.15535474° E.: 15.22962503°	967 *m*	Steppe vegetation
Saline di Siracusa 1	SS1	N.: 37.04795785° E.: 15.27232781°	5 *m*	Halophilic and psammophilous vegetation
Saline di Siracusa 2	SS2	N.: 37.05354458° E.: 15.27004659°	1 *m*	Psammophilous vegetation
Saline di Priolo 1	SP1	N.: 37.145555° E.: 15.211388°	213 *m*	Weed vegetation
Saline di Priolo 2	SP2	N.: 37.142802° E.: 15.218645°	163 *m*	Weed vegetation
Vendicari 1	VE1	N.: 36.806567° E.: 15.101946°	45 *m*	Thermophilic sclerophylls
Marianelli 1	MA1	N.: 36.83089° E.: 15.10128°	1700 *m*	Thermophilic sclerophylls
Calamosche 1	CA1	N.: 36.82163° E.: 15.10598°	667 *m*	Thermophilic sclerophylls
Cittadella 1	CI1	N.: 36.77775° E.: 15.09280°	298 *m*	Thermophilic sclerophylls

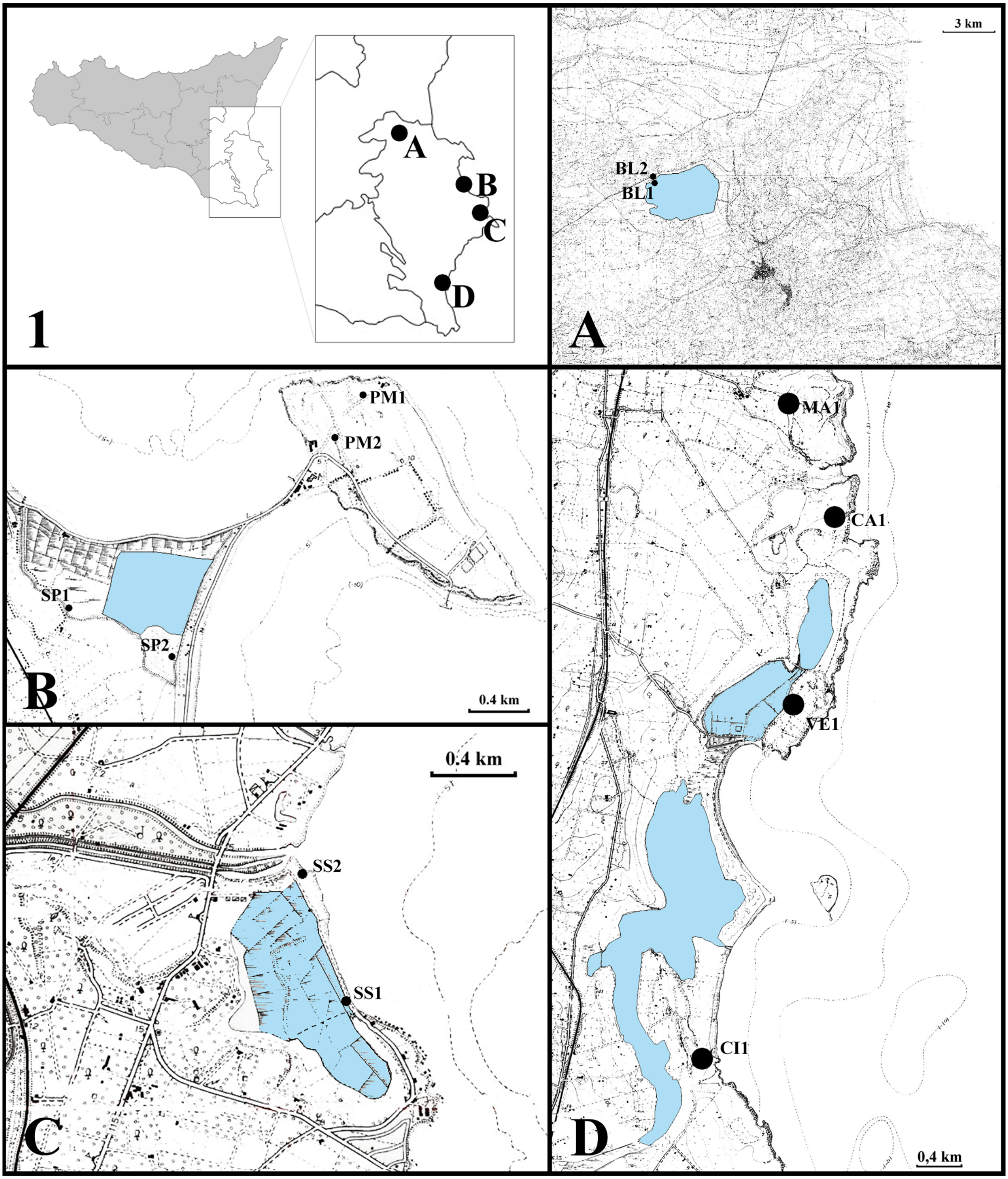

Fig. 1. Maps of sampling sites. **1**. Localization in south-eastern Sicily of the four sampling areas.; **A**. Biviere di Lentini (BL1, BL2). **B**. Saline di Priolo (SP1, SP2) e Penisola di Magnisi (PM1, PM2). **C**. Saline di Siracusa (SS1, SS2). **D**. Vendicari wildlife oasis: Vendicari (VE1), Cittadella (CI1), Marianelli (MA1), Calamosche (CA1). In light blue the water basins within the studied areas. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.2. Sampling phase

Each site was sampled twice, in spring (April 2021) and autumn (November 2021).

In each sampling site, for sorting the arthropod fauna, a total amount of three soil samples at the vertices of a triangle 10 m apart were taken using a corer with dimensions 10x10x10 cm. The three core samples from each vertex (about 3000 cm^3) were collected in a single polyethylene bag. For each sampling site, a form was compiled with the following data: date, time, GPS coordinates, soil and atmospheric temperature and vegetation. In addition, a single core (10x10x10 cm) was taken for each site to assess soil chemical-physical parameters.

2.3. Extraction and identification

Fauna was extracted using Berlese-Tullgren selectors for 14 days. Then, the material collected was observed and sorted under the stereomicroscope. For each specimen/taxon, the EMI value was assigned for the calculation of the QBS-ar and the Number of Taxa (NT) and individuals per *taxon* (NI) was counted. Samples with excessive presence of sediment were washed before observation with a supersaturated salt solution to separate the animals from the excess mineral particulate.

2.4. Physical and chemical properties of the soil

Physical and chemical soil properties were determined using standard, internationally recognized methods.

Organic matter (OM) was measured according to Springer and Klee (1954). The determination of pH was carried out using a glass membrane electrode in distilled water (soil/ water ratio 1:2.5 (w/v)) an AB 15 pH meter (Thermo Fisher Scientific, Waltham, MA, USA); soil electrical conductivity (EC) and total dissolved solids (TDS) in distilled water (soil/water ratio 1:5 (w/v)) using an HI 9813 portable EC-TDS meter (Hanna Instruments, Woonsocket, RI, USA); Total carbonates content through the Dietrich–Fruehling's calcimeter; active limestone determined with ammonium oxalate [(NH4h C20 4.H20] solution 0,2N and potassium permanganate (KMn04) solution 0,1N; texture (sand, 2–0.02 mm; silt, 0.02–0.002 mm; clay, $<$ 0.002 mm) by pipette method.

2.5. Statistical analysis

The data obtained (QBS-ar values, NT, NI) were analyzed by one-way Analysis of variance (ANOVA) to investigate the difference between sampling sites and between seasons. In those comparisons in which significant differences emerged, post hoc analysis was performed using the Tuckey HSD/Kramer test (Sokal & Rohlf 1995).

T-test was performed to compare the seasonal difference in the number of individuals for each taxon. Pearson correlation coefficient was used to correlate the average chemical/physical parameters with the average QBS-ar of each sampling site and with the taxa abundances.

These statistical analyses were performed using the Real Statistics Resource Pack software (Release 7.6) Copyright (2013 – 2021) Charles Zaiontz. https://www.real-statistics.com (Zaiontz, 2013). The significance limit for the statistical analyses was fixed at $p = 0.05$.

In addition, a principal component analysis was carried out on EMI data to evidence the differences in community structures between sampling sites. A bootstrap resampling technique with 1,000 replicates was used. For the significance of eigenvector coefficients, a 95% confidence limit was considered.

Before performing PCA, Acari, Collembola, Lepidoptera (larvae), Coleoptera (larvae), Diptera (larvae and adults), Hymenoptera and Isopoda were removed from the analysis because present in all samples with constant EMI values. Orthoptera, Trichoptera, Isoptera and Dermaptera were excluded from the analysis due to being present in only one sample and due to contributing negligibly to QBS-ar value. PCA was performed using the Past program, version 2.17c (Hammer et al. 2001).

3. Results

3.1. Fauna

A total of 24 taxa were identified for the calculation of QBS-ar: Araneae, Opiliones, Pseudoscorpiones, Acari, Isopoda, Chilopoda, Diplopoda, Symphyla, Pauropoda, Collembola, Protura, Diplura, Hemiptera, Coleoptera, Psocoptera, Hymenoptera, Thysanoptera, Embioptera, Isoptera, Dermaptera, Orthoptera, Lepidoptera, Diptera and Trichoptera.

There was a total of 26,056 microarthropod individuals, of which 16,209 in spring (Table 2) and 9847 in autumn (Table 3). Acari, Collembola, Coleoptera and Diptera were always present in all samples. The frequency in the samples of some taxa increased, sometimes conspicuously, from Spring to Autumn: Protura and Embioptera were found respectively in 4 and 1 samples in spring and in 9 and 4 in autumn. Psocoptera, Diplopoda, Pauropoda, and Opiliones decrease from spring to autumn: respectively 8 vs 2, 10 vs 7, 7 vs 3, 5 vs 1.

Overall Acari and Collembola represented 75.8% of all the fauna sampled (52.3 and 23.5% respectively). In all the samples Orthoptera, Lepidoptera (larvae), Isoptera, Dermaptera and Trichoptera are represented by a single specimen and can be considered occasional in the sampled sites. In the area of Vendicari (sites VE1, MA1, CI1, CA1), in the entire year, the high number of Symphyla represent 19,2% of all the fauna sampled in the areas, excluding Acari and Collembola.

The average value of the number of individuals is statistically higher in spring than in autumn for Pseudoscorpiones ($p < 0.05$), Hymenoptera

Table 2
Distribution and abundance of taxa collected in spring samplings. Values of QBS-ar index, Number of Individuals (NI) and Taxa (NT).

SPRING SAMPLIG												
Taxon	**BL1**	**BL2**	**SS1**	**SS2**	**SP1**	**SP2**	**PM1**	**PM2**	**VE1**	**MA1**	**CI1**	**CA1**
Acari	678	930	235	288	1012	266	693	364	1507	957	894	463
Araneae	6	5	2	2	5	10	2	8	5	1	2	2
Chilopoda				2	15	1	1		18	4	12	2
Coleoptera	13	25	23	149	6	3	16	5	17	8	1	3
Coleoptera larvae	59	56	5	41	26	18	68	131	5	3	4	1
Collembola	263	497	46	44	320	21	18	40	1020	409	232	344
Diplopoda	34	19	23		94	40	3		11	5	7	3
Diplura	3	32	17		29	4		4	67	19	10	2
Diptera	1	2	1	1	1	2	1		14	12	16	11
Diptera larvae	6	4	1	7	1	9		3	31	4	3	1
Embioptera										1		
Hemiptera	88	20	3		24	38	20	38	5	6	2	3
Hymenoptera	15	619	94	92	185	30	627	113	270	9	12	131
Hymenoptera larvae			1	7		1	18					
Isopoda	25	22		7	1	69	1	17	7	6	4	1
Opiliones	31	1	1			1					1	
Pauropoda		2			48			8	4	2	1	3
Protura									34	11	2	3
Pseudoscorpiones	12	25	4		57		1	8	26	34	13	7
Psocoptera	5	2	12			2	2	5	1	1		
Symphyla	2	9			6			4	117	53	80	39
Thysanoptera		2				1		3				
Trichoptera									1			
N. Individui	**1241**	**2272**	**468**	**640**	**1830**	**516**	**1471**	**751**	**3160**	**1545**	**1296**	**1019**
N. Taxa	**16**	**18**	**15**	**11**	**16**	**17**	**14**	**15**	**19**	**19**	**18**	**17**
QBS-ar	**181**	**214**	**164**	**116**	**202**	**165**	**148**	**164**	**234**	**248**	**233**	**223**

Table 3
Distribution and abundance of taxa collected in autumn samplings. Values of QBS-ar index, Number of Individuals (NI) and Number of Taxa (NT).

AUTUMN SAMPLIG												
Taxon	**BL1**	**BL2**	**SS1**	**SS2**	**SP1**	**SP2**	**PM1**	**PM2**	**VE1**	**MA1**	**CI1**	**CA1**
Acari	741	220	221	107	63	90	593	45	433	950	1373	493
Araneae	2	17			1	2	4	4	1	2	2	1
Chilopoda		9	2		2	4	4	2	10	14	14	5
Coleoptera	3	8	4	8	25	8	2	2	6	4	3	3
Coleoptera larvae	35	3	16	61	7	15	17	7		10	9	1
Collembola	349	255	273	284	180	81	383	42	362	223	177	267
Dermaptera					1							
Diplopoda		12	3		27			1	1	7	1	
Diplura	11	16			14	7		3	6	6	4	7
Diptera	2	2	4	9	2	3	3	2	10	23	12	4
Diptera larvae	1	10	2	51	5	11	12	7	18		55	14
Embioptera						1			3	4	1	
Hemiptera	81	6			7	12	23	6	2	77	8	
Hymenoptera		5	5	6	12	21	3	8	69	84	2	1
Isopoda	6	19	4	9	2	17		10	6	10	5	1
Isoptera					1							
Lepidoptera larvae	2											
Opiliones		2										
Orthoptera									1			
Pauropoda	1									3	15	
Protura		7	4	3	18	1			29	29	8	2
Pseudoscorpiones	1	15			1		1		8	21	7	1
Psocoptera	1									1		
Symphyla		12	9		13	15	20	8	8	23	38	15
Thysanoptera	5									2	1	6
NI	**1241**	**618**	**547**	**538**	**381**	**288**	**1065**	**147**	**973**	**1493**	**1735**	**821**
NT	**15**	**17**	**12**	**9**	**18**	**15**	**12**	**14**	**17**	**19**	**19**	**15**
QBS-ar	**164**	**222**	**161**	**106**	**228**	**192**	**137**	**172**	**219**	**239**	**245**	**183**

($p < 0.01$), Diplopoda ($p < 0.05$), Psocoptera ($p < 0.05$) and Coleoptera ($p < 0.05$). As far as fauna analysis is concerned, the highest number of individuals was found in the site of VE1 in spring and the lowest number at site 2 on the PM2 in autumn (Tabs. 2, 3; Fig. 2). The high number of individuals of VE1 statistically differentiates the sites from CA1 ($p < 0.005$), SP2 ($p < 0.002$), SS1 ($p < 0.005$), SS2 ($p < 0.005$) and PM2 ($p < 0.002$).

An increase is observed in the spring period; this is not the case for sites SS1 and CI1, where the period with the greatest number of individuals is autumn. The only statistically significant differences between autumn and spring concern SP1 ($p < 0.02$), BL2 ($p < 0.01$) and VE1 ($p < 0.05$).

The highest number of taxa was found in both seasons in MA1 (19); the same value was found in autumn in CI1 and in spring in VE1. The lowest value (9) was found in autumn in SS2 (9) (Tabs. 2, 3; Fig. 3). The statistical analysis divides the sites into three groups: in the first group are VE1 and MA1, both differing from BL1 (respectively $p < 0.005$, $p < 0.002$) PM1 ($p < 0.001$, $p < 0.001$), PM2 ($p < 0.005$, $p < 0.002$), SS1 ($p < 0.001$, $p < 0.001$), SS2 ($p < 0.001$, $p < 0.001$), SP2 ($p < 0.005$, $p < 0.002$), CA1 ($p < 0.002$, $p < 0.001$); in the second group are CI1 and BL2, which differ from PM1 ($p < 0.002$, $p < 0.005$), SS1 ($p < 0.005$, $p < 0.001$), SS2 ($p < 0.001$, $p < 0.001$); the third is represented by SP1 alone

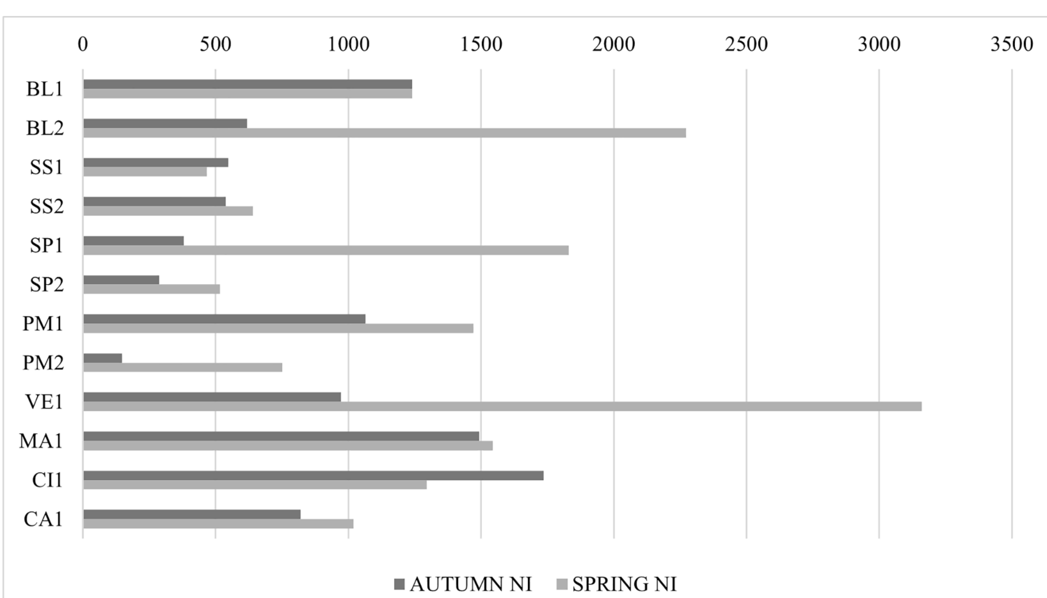

Fig. 2. Trend of NI in the sampling sites in autumn and spring.

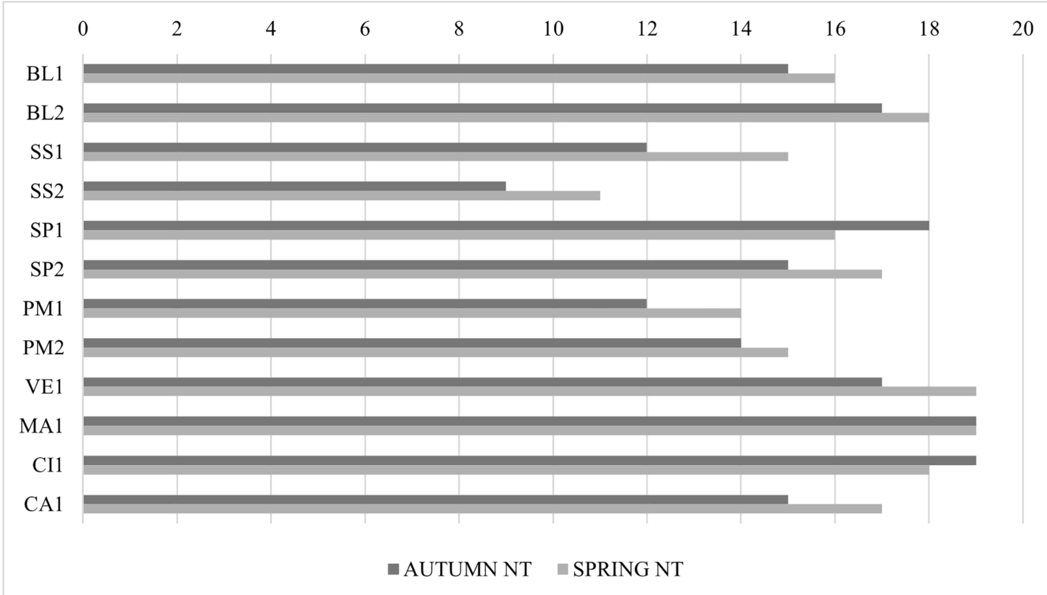

Fig. 3. Trend of NT in the sampling sites in autumn and spring.

that differs from PM1 ($p < 0.005$) and SS2 ($p < 0.002$). On the other hand, no significant difference can be found in the number of taxa recorded in the two seasons, with negligible increases in spring.

The analysis of euedaphic groups (EMI 20) shows a higher number of taxa in MA1 and CI1 sites in autumn, and in CA1 and VE1 in spring (9). The lowest number (2) is instead found in SS2 in spring (Table 4).

Some taxa show positive correlation with the percentage of silt: Acari ($r = 0.80$; $p < 0.005$), Collembola ($r = 0.76$; $p < 0.005$), Pseudoscorpiones ($r = 068$; $p < 0.05$), Protura ($r = 0.74$; $p < 0.01$), Diplura ($r = 0.75$; $p < 0.005$), Symphyla ($r = 0.70$; $p < 0.05$). They are negatively correlated with the % of sand Acari ($r = -0.68$; $p < 0.05$), Collembola ($r = -0.63$; $p < 0.05$), Pseudoscorpiones ($r = -0.62$; $p < 0.05$), Diplura ($r = -0.65$; $p < 0.05$). Negative correlation also exists between the percentage of total limestone and Acari ($r = -0.93$; $p < 0.001$), Collembola ($r = -0.63$; $p < 0.05$), Pseudoscorpiones ($r = -068$; $p < 0,05$), Protura ($r = -0.63$; $p < 0.05$), Symphyla ($r = -0.70$; $p < 0.05$).

The other parameters analysed produced no correlation.

3.2. QBS-ar

The lowest QBS-ar value was found in both seasons in SS2, while the highest QBS-ar values were recorded in the Sites sampled within the RNO Vendicari (except for CA1 in autumn) (Tabs. 2, 3; Fig. 4).

The statistical analysis regarding annual QBS-ar divides the sites into two groups with significant differences between them, a group consisting of SP1, MA1, CI1, VE1, BL2 with overall QBS-ar > 200 and a group consisting of BL1, SP2, PM1, PM2, SS1, SS2 with overall QBS-ar < 200. CA1 site shows no significant difference between the two groups (QBS-ar in autumn 183, in spring 223) except or CI1, from which it differs by the latter's high QBS-ar value (245 in autumn) (Table 5).

In all the sampled areas, there are also no major seasonal differences in QBS-ar.

3.3. Influence of chemical-physical parameters on the composition of soil microarthropod fauna and QBS-ar

According to the chemical-physical analyses (Table 6), the area with the highest electrical conductivity (E.C.) was found in BL2, with E.C. values of 4.76 mS/cm; E.C. value in SS2 was equally high, with a value of 4.38 mS/cm. The lowest C.E. values were found in CA1 with electrical conductivity values of 0.58 mS/cm.

For the main chemical-physical parameters, correlation analysis was conducted with QBS-ar and NI. For both, strong positive correlation exists with the percentage of silt (respectively $r = 0,69$; $p < 0,05$; $r = 0,92$; $p < 0,001$) (Fig. 5a), a negative correlation with the percentage of sand ($r = -0,64$; $p < 0,05$; $r = 0,80$; $p < 0,005$) (Fig. 5b) and total

Table 4
Number of Taxa found in the sampling sites divided by EMI in spring and autumn.

	Spring								Autumn					
	EMI								EMI					
	20	15	11	10	8	6	5	1	20	16	15	10	5	1
BL1	6	–	–	4	1	–	2	3	5	–	1	4	1	4
BL2	8	–	–	4	–	–	2	4	8	–	–	5	2	2
SS1	5	1	–	4	–	–	1	4	6	–	–	3	2	1
SS2	2	1	–	5	–	–	2	1	3	–	–	4	1	1
SP1	7	–	–	5	–	–	2	2	8	–	1	4	2	3
SP2	4	–	1	6	–	–	2	4	7	–	–	3	2	3
PM1	4	1	–	4	–	–	2	3	5	–	–	2	3	2
PM2	5	1	–	3	–	1	2	3	6	–	–	4	2	2
VE1	9	–	–	4	–	–	2	4	8	1	–	3	1	3
MA1	9	1	–	4	–	–	2	3	9	–	1	3	2	4
CI1	9	–	–	4	–	–	2	3	9	1	–	3	1	4
CA1	9	–	–	3	–	–	2	3	7	–	–	3	2	3

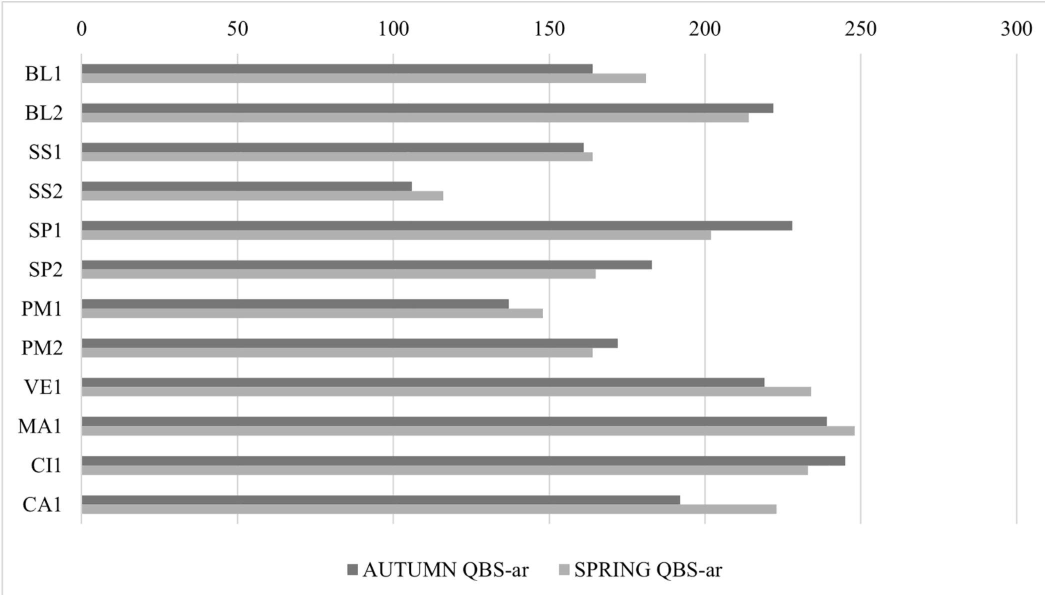

Fig. 4. Trend of QBS-ar values in the sampling sites in autumn and spring.

Table 5
p-values of ANOVA on annual QBS-ar values (ns = not significant).

	SP2	PM1	PM2	SS1	SS2	BL1	CA1
SP1	<0,05	<0,001	<0,005	<0,005	<0,001	<0,01	ns
MA1	<0,05	<0,001	<0,001	<0,001	<0,001	<0,005	ns
CI1	<0,005	<0,001	<0,001	<0,001	<0,001	<0,001	<0,05
VE1	<0,05	<0,001	<0,001	<0,001	<0,001	<0,005	ns
BL2	ns	<0,005	<0,005	<0,005	<0,001	<0,05	ns

Table 6
Chemical-physical parameters of the sampled soils.

	Clay %	Silt %	Sand %	Ph	Electrical conductivity mS/cm	Total dissolved solids mg/l	Active limestone %	Total limestone %	Organic matter %
BL1	36.75	18.70	44.55	8.04	2.39	227.00	10.30	27.24	4.86
BL2	47.00	33.95	19.05	8.00	4.76	300.00	12.34	21.43	6.10
SS1	15.70	12.40	71.90	7.80	1.01	200.00	5.49	53.59	7.81
SS2	5.60	7.20	87.20	8.83	4.38	850.00	4.07	64.30	5.44
SP1	20.75	28.60	50.65	7.61	2.41	1206.00	6.72	25.38	9.57
SP2	16.95	12.20	70.85	7.83	1.34	672.00	8.27	60.07	7.79
PM1	19.55	30.85	49.60	7.61	1.12	208.00	1.48	21.43	8.56
PM2	8.25	17.10	74.65	7.81	0.72	145.00	3.89	47.33	7.67
VE1	13.80	46.15	40.05	7.55	0.96	176.00	1.64	4.91	7.96
MA1	16.70	33.05	50.25	7.67	0.92	170.00	1.97	6.70	7.39
CI1	21.90	30.25	47.85	7.59	1.23	223.00	1.58	6.70	8.86
CA1	14.90	16.75	68.35	7.78	0.58	107.00	4.01	53.59	4.62

limestone ($r = -0,70$; $p < 0,05$; $r = 0,92$; $p < 0,001$) (Fig. 5c). Only QBS-ar is negatively correlated with pH ($r = -0,66$; $p < 0,05$) (5d).

The other parameters analyzed reported no correlation.

3.4. PCA

Overall, the first two components contain 64.45% of the total variance. The first component (43.24% of the variance) shows strong positive correlation with QBS-ar values ($r = 0.84$; $p < 0.001$) (Fig. 6) and therefore the distribution of the sites along PC1 reflects the quality of the sites examined (Fig. 7). Most sites (8) are located in the positive part of PC1, 4 in the negative. The taxa that most positively influence PC1 are Diplopoda, Chilopoda, Diplura, Symphyla, Pauropoda (the only significant one) and Pseudoscorpiones, all at EMI 20. Only Hymenoptera larvae gave significant negative contribution to PC1 (Fig. 8). PC2 is significantly related to the presence of Protura (Fig. 9) and discriminates sites based on the presence/absence of this group.

4. Discussion

4.1. Fauna

The main euedaphic taxa typical of well-preserved and stable soils (Protura, Diplura, Pauropoda, Symphyla and Pseudoscorpiones) were found in most sampled sites.

Protura are a group that rarely occur but their ecological and morphological characteristics make them an indicator of soil stability (Blasi et al., 2013; Socarrás, 2013; Christian and Szeptycki, 2004). However, they are resistant to periodic inundation typical of wetlands (Sterzyńska et al., 2012) and find in these environments a favorable

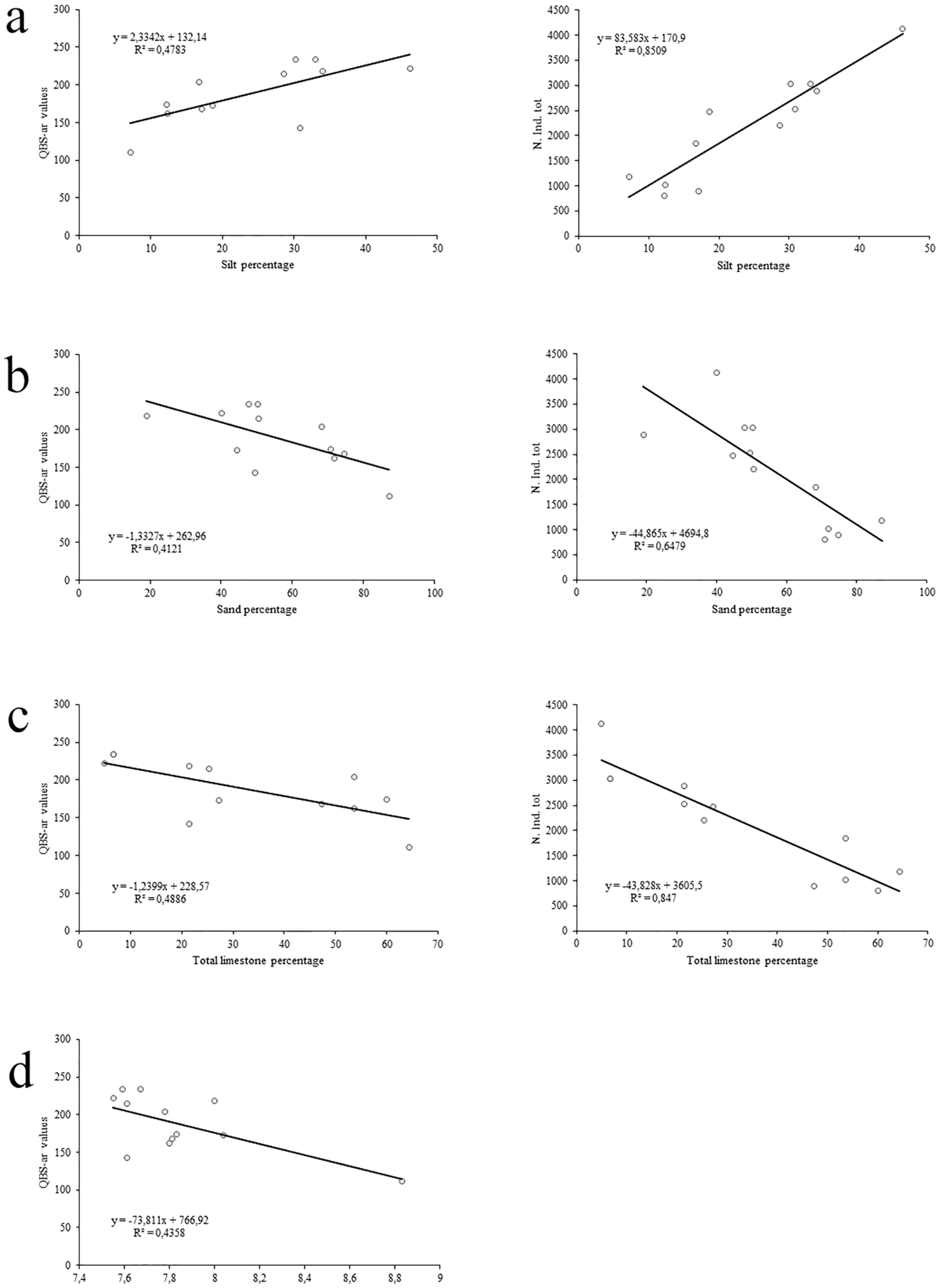

Fig. 5. Linear correlations between QBS-ar and NI with silt percentage (**a**), Sand percentage (**b**), total limestone (**c**) and, only for QBS-ar, with pH (**d**).

habitat (Marx et al., 2016). Furthermore, Protura are considered by various authors as a key group, together with the value of the QBS-ar, for assigning the quality classes to the soils (Parisi, 2001; D'Avino, 2002; Griselli, 2007).

Also in the present study, Protura were detected as an important group to assess soil quality. As a matter of fact, PCA distinguishes the sites with low or higher soil quality not only by Qbs-ar values but also due to the absence of Protura, a group with which the PC2 is clearly correlated.

In the sampling sites under investigation, this group was present in spring only in the four sites within the RNO Vendicari. In autumn we found it in all sites except for PM1 and PM2. The autumn season seems to be favorable to Protura with a higher number of individuals found in November. This agrees with the observations of Galli et al., 2012 which reported seasonal numerical fluctuations of this group with a decrease in the number of individuals in the driest periods. Mitrovski and Blesic (2006, 2011) detected early spring as a period of decline in proturan abundance due to the migration of individuals into soil layers deeper than 20 cm. In the Mediterranean areas Protura are forced to move up and down the soil profile in response to temperature and moisture levels

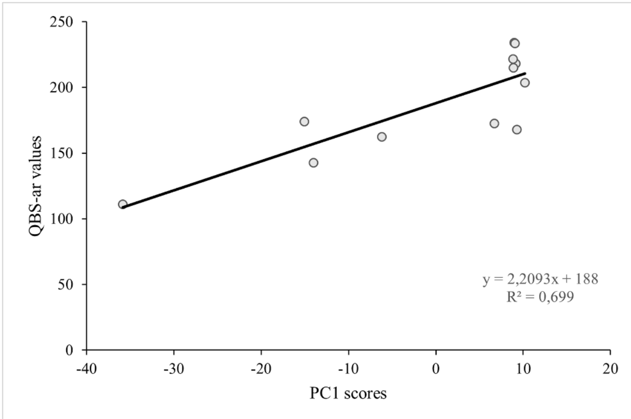

Fig. 6. Positive linear correlation between PC1 coordinates and QBS-ar values.

(Galli et al., 2020). We therefore consider that the lower presence in spring in the sampled sites is related to the fact that only the first 10 cm of soil were sampled.

Diplura are associated with soils with a low level of disturbance (Suárez et al., 2018). As a confirmation, the sites of our study where Diplura were missing are affected by disturbances of natural origin (high salinity of SS2 due to proximity to the sea) and anthropic (grazing in PM1 and deposition of waste material in SS1).

Pauropoda also have high sensitivity to stress and are mainly found in undisturbed soils (Vignozzi et al., 2019; Menta and Remelli, 2020); the presence in MA1 and CI1 sites also in the autumn season agrees with the excellent quality of soils demonstrated for these two sites with high QBS-ar value in both periods.

Symphyla were absent in both seasons only in SS2, a fact probably determined by the high salinity already mentioned.

Pseudoscorpions are a group of predatory arthropods related to stable environments (Menta and Remelli, 2020) and need a complex and well-structured community of soil fauna. This group is present in most of sampled sites, confirming the good complexity of the communities of the sites analysed. Their spring increase is probably determined by the general numerical rise of individuals in this season, therefore also of their potential preys.

4.2. QBS-ar

The QBS-ar values recorded are all higher, for both seasons, than the averages reported for land use by Menta et al. (2018). For the sampled sites of the present study, we obtained QBS-ar values not lower than 106 (such minimum value in SS2 in autumn), while in general we observe much higher values in the various sites for both seasons; therefore, all values of our study were far higher than 93.7, which Menta et al., 2018 defined as a partition between soils that are associated to good quality from those that are degraded or considered of lower quality.

The statistical elaborations (ANOVA, Tuckey/Kramer test and PCA) clearly distinguish the sites with high quality soils from the more disturbed ones, confirming that the RNO Vendicari has the best natural conditions and that SS1 and the sites of the Penisola di Magnisi are more affected by anthropization. The high electrical conductivity present in SS2 probably influences the value of QBS-ar.

Although there are seasonal fluctuations in the number of specimens in the single sampling sites, no significant differences are recorded either in the number of taxa or in the QBS-ar values, as also noted in other environments (Blasi et al., 2013). This confirms that the synthesis made by the QBS-ar index allows an assessment of soil quality regardless of the obvious seasonal variations of the edaphic communities.

4.3. Influence of chemical-physical parameters on the composition of soil microarthropod fauna and QBS-ar

The chemical-physical parameters that seem to influence the composition of the fauna and the QBS-ar were mostly those related to the soil texture, as demonstrated also by other authors (Briones, 2018; Ghiglieno et al., 2021; Tao et al., 2019). The increase in silt content and the decrease in sand are correlated with an increment in abundance of some euedaphic groups and in QBS-ar values. The presence of some taxa is also influenced by the percentage of total limestone.

The QBS-ar instead shows a further negative correlation with soil pH, although Moço et al. (2010) reported significant positive direct effect on richness of fauna.

The highest E.C. value found in the soil of BL2 is probably due to the high total limestone percentage of this substrate, given the considerable distance from the sea. BL2 also has the highest percentage of active limestone among the sites analysed. The presence of calcium carbonate increases the conductivity of these soils, a fact that does not seem to affect the edaphic arthropod communities (as evidenced by the high values of QBS-ar, Number of individuals and Number of Taxa).

Fig. 7. Principal Components Analysis (PCA) scatter plot of EMI data.

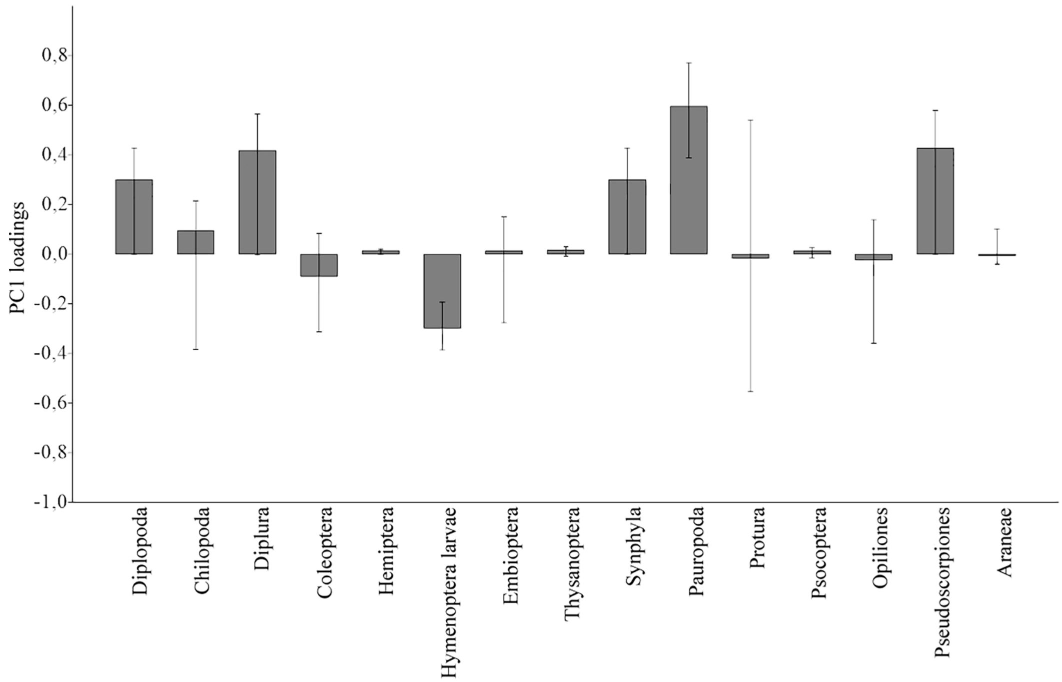

Fig. 8. 95% Bootstrap confidence intervals of PC1 factor loadings.

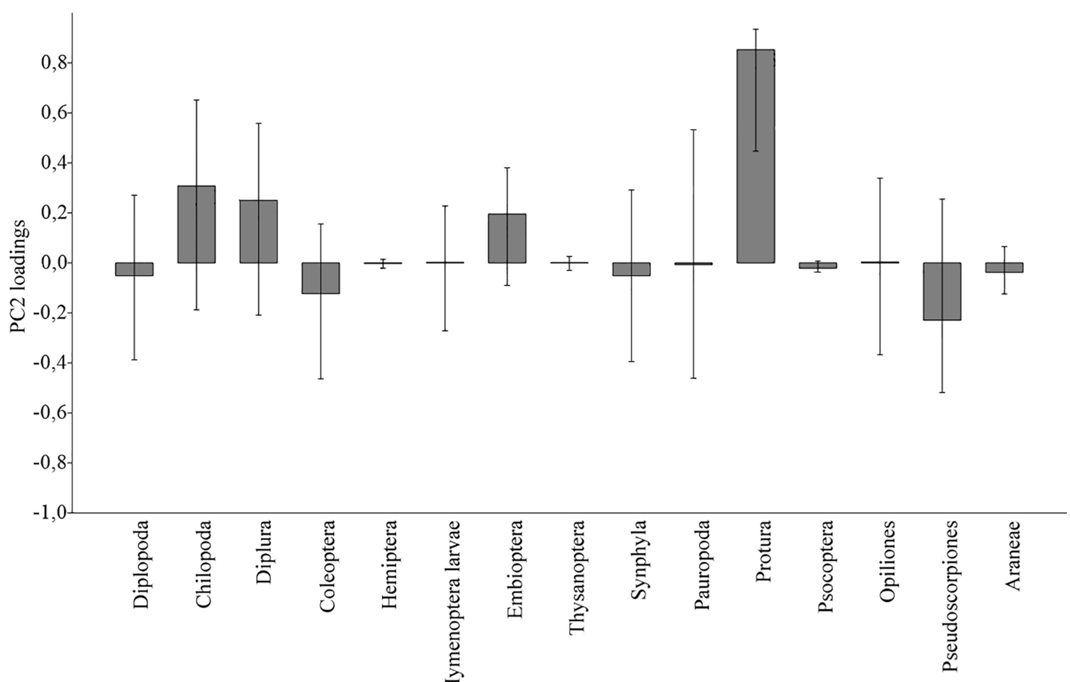

Fig. 9. 95% Bootstrap confidence intervals of PC2 factor loadings.

The E.C. value equally high in SS2 is reflected in the edaphic communities, as demonstrated by the significantly lower QBS-ar value. In this case the high E.C. is due to NaCl deposits because of the extreme proximity to the sea, fact that limits the edaphic arthropod communities as demonstrated by Desender & Maelfait (1999) and Pan et al. (2018). Further studies are needed to assess better this limiting factor on soil fauna.

5. Conclusions

The results obtained demonstrate a good quality of soils and a rather rich population of arthropod fauna in almost all sampled sites. They represent the first data relating to the QBS-ar in Sicily and, in particular, relating to wetlands. The high values of QBS-ar and the data relating to the abundance of fauna confirm the importance of conservation of these areas.

As a matter of fact, the entire area of Vendicari, the first wetlands of eastern Sicily established as a reserve, maintains the best soil quality and the richest arthropod fauna.

The proximity to a water basin does not determine variations in the composition of the fauna and in the QBS-ar values, that seem to be more influenced by the soil texture, by some chemical parameters and by the presence of natural and anthropic disturbances.

Lastly, this study further confirms the ability of the QBS-ar index to detect, in a simple and rapid way, soil quality regardless of seasonal variations of the edaphic communities.

Furthermore, the collection and analysis of the large amount of data carried out in this study will constitute a basis for further studies on the subject.

CRediT authorship contribution statement

Diego Leone: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Marilena Mirabile:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Giambattista Maria Altieri:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Andrea Zimone:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Biagio Torrisi:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Eustachio Tarasco:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Mirella Clausi:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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