Pedofaunistic and soil investigation in Scots pine forests in the Aosta Valley and Piedmont (northwest Italy)

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Four sites in the Aosta Valley and four sites in Piedmont were selected for this purpose; the Aostan ones are considered pine stands suffering from a dieback of Scots pines probably deriving from increased drought conditions in the past two-three decades. The pedofaunistic investigation pointed out fully differentiated and balanced microarthropod communities living in rather well developed soils. The sampling method, following the QBS standard, together with the abundances of key taxa, and the statistical analyses adopted, show how close the integration of pedologic and pedofaunistic expertises must be to understand population dynamics and the environmental parameters influencing them, and how thorough the pedofaunistic investigation must be to assess correctly the presence/absence of key taxa when evaluating the biological quality of soils.

Key words: *Pinus sylvestris*, Biological index of soil quality, arthropods, pedofauna.

INTRODUCTION

The increasing demand of using bioindicators or synthetic monitoring indexes for environmental impact assessments has resulted in plenty studies, most of which concern the quality of aquatic environments (Woodwiss, 1978; Lebrun, 1981; Blandin & Lamotte , 1985; Blandin, 1986; Ghetti, 1997). Concerning the soil, until recently it was among the least known habitats; still today the edaphic biota remains mostly unexplored. However, the need to detect the biological quality of these coenoses has encouraged researchers to focus their attention on the soil fauna. Many soil organisms are generally sensitive to changes of either natural or anthropic origin and to the chemiophysical balance that characterizes the soil, and thus can be considered good indicators (Curry, 1987; Paoletti *et al.*, 1991, 1995; Marra & Edmonds, 1998; Osler *et al.*, 2001; Parisi, 2001). In particular, some scholars have focused their attention only on certain groups such as Nematoda (Bongers, 1990), Annelida (Paoletti, 1998, 1999), Acari Oribatidae (Behan-Pelletier, 1999), Isopoda (Paoletti & Hassal, 1999), Pauropoda (Hågvar & Sheller, 1998), Collembola (Hopkin, 1997), Diptera (Frouz, 1999) and Hymenoptera Formicidae (Majer & Benston, 1996; Anderson, 1997), to provide useful important indications on the biological quality of soils.

Several soil biological quality indexes have been proposed, based on the presence of arthropods in the soil populations (Casarini *et al.*, 1990; Parisi, 2001; Nizzoli *et al.*, 2004). They permit to detect synthetically any changes in the pedofauna, thus giving valuable information on the health status of the soil and, indirectly, of the ecosystem of which it is a part. It is good to specify that the risk that can usually be run in the use of quality indexes – especially when complex systems such as trophic networks and the soil are dealt with – is the excessive synthesis of information.

The index here used to assess soil quality in the sampling sites is the Biological Index of Soil Quality (QBS), which is obtained by summing the eco-morphological indexes (EMI) of the *taxa* found (Parisi, 2001).

In this study we propose a survey of the soil fauna in Scots pine (*Pinus sylvestris* L.) woods in the Aosta Valley, where the plants are under stress and in some cases appear to be at risk of die-back, and Piedmont, where the conditions of the pines appear good (Vacchiano *et al.*, 2008).

The pedologic survey was carried out to know better the soil environment in which the soil fauna lives and to point out possible physico-chemical parameters influencing the arthropod community.

MATERIALS AND METHODS

Selected sites

As part of an Italian-Swiss Interreg project on the dieback of Scots pine (*Pinus sylvestris* L.) 4 sites were selected in the Aosta Valley and 4 control sites in northern Piedmont (Fig. 1) (northwest Italy).

The sites checked in the Aosta Valley were:

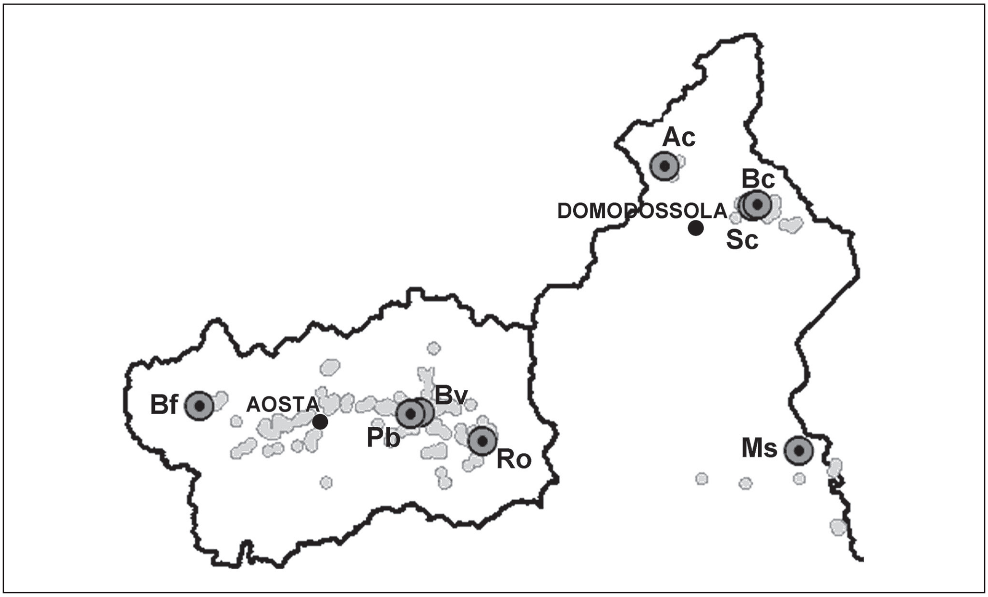

Fig. 1 - Area of Scots pine (*Pinus sylvestris* L.) in the Aosta Valley and in Piedmont (gray) and location of the sampling sites (Aosta Valley: Bf, Bois de Feisouilles; Bv, Bois de Vorpeillère; Pb, Petit Bruson; Ro, Rouvère. Piedmont: Ac, Alpe Ciona; Bc, Bosco della Colma; Ms, Monte Solivo; Sc, Scarliccio).

Bf: Bois de Feisouilles (Morgex) (N 5069859 E 344753).

This is a forest of about 80 years of age, with a prevalence of Scots pine on pubescent oak, and the presence of spruce, larch and heliophilous broadleaf trees. It is classified as an endalpic basiphilous pinewood. The mean elevation is 1,091 m, with a southern exposure and the average slope is 77%.

Bv: Bois de Vorpeillère (St. Denis) (N 5068444 E 389978).

This is a forest of about 125 years of age in which the Scots pine dominates the red spruce, with occasional presence of larch, and can be classified as an endalpic basiphilous Picea and pine forest. The mean elevation is 1,350 m, with a south-west exposure and an average slope of 34%.

Pb: Petit Bruson (St. Denis) (N 5068071 E 387870).

The site, exposed south-west with an average slope of 62%, is characterized by the presence of a vast pine forest of Scots pine, irregularly mixed with pubescent oak. The forest type can be classified as an endalpic basiphilous pine forest. The forest of 20-30 years of age is at the mean elevation of 985 m.

Ro: Rouvère (Challand-St-Anselme) (N 5062482 E 402270).

This is a forest of about 90 years of age, in which the Scots pine dominates the chestnut, and it can be classified as a mesalpic acidophilous pine forest. The mean elevation is 1,116 m, with a west exposure and an average slope of 40%.

The sites checked in Piedmont were:

Ms: Monte Solivo (Borgo Ticino, province of Novara) (N 5060489 E 467254).

This is a flat wood of Scots pine mixed with chestnut coppice, oak and birch trees, and is classified as a heathland pine forest. The forest, of about 100 years of age, is at the mean elevation of 320 m.

Sc: Scarliccio (Santa Maria Maggiore, province of Verbano-Cusio-Ossola) (N 5110657 E 457763).

It is a Scots pine forest, approximately 60 years of age, with regeneration of spruce and fir and invasion of birch, and is classified as a mesalpic acidophilous pinewood. The mean elevation is 1,050 m, with an eastern exposure and an average slope of 40%.

Bc: Bosco della Colma (Toceno, province of Verbano-Cusio-Ossola) (N 5110964 E 458567).

It is a Scots pine forest, 90-130 years of age, with regeneration of beech, fir and spruce, and is classified as a mesalpic acidophilous pine forest. The mean elevation is 1,050 m, with a western exposure and an average slope of 80%.

Ac: Alpe Ciona (Trasquera, province of Verbano-Cusio-Ossola) (N 5118744 E 439503).

This is a Scots pine forest, with the presence of larch and undergrowth of rhododendron, and is classified as a mesalpic acidophilous pine forest. The forest, 100-130 years of age, has a mean elevation of 1,247 m, a south-west exposure, and an average slope of 30%.

<u>Pedofaunistic analysis</u>

Sampling was carried out once in late spring and once in late summer/beginning autumn, namely: 9-10 June and 15-16 September 2005 in Piedmont and 30-31 May and 4-5 October 2005 in the Aosta Valley. Three soil samples were collected per each site in areas as homogeneous as possible concerning canopy cover, making sure not to be in the presence of special conditions that could cause alterations in the structure of the soil fauna, such as heavily compacted soil, groundwater outcrops, strong slopes or concavities, ant nests or tree roots.

The soil temperature was recorded before to extract the clod of soil sized 10x10 with thickness of max 10 cm when possible.

In the laboratory, the soil was weighed and placed inside Berlese-Tullgren selectors (Martin, 1977; Edwards, 1991). The extraction of the arthropods lasted 7-10 days depending on the water content of the sample. The soil fauna was preserved in 70° alcohol. The water content (RH) of the soil was calculated by weighing the dry sample after the extraction of soil fauna and, subtracting this weight from the fresh weight and dividing the result by the dry weight.

After the extraction, the analysis of the collected specimens was carried out by pouring the sample into petri dishes and using a stereo microscope for classifying and counting. The data collected were processed using the QBS method (Parisi, 2001; modified by D'Avino, 2002).

Pedologic survey

Soil material was collected from excavated profile pits. Due to the stony character of the soils, around 4 to 5 Kg of soil material was collected per soil horizon. In order to yield reasonable results, large soil sampling volumes are needed for soils in Alpine areas (Hitz *et al.*, 2002; Egli *et al.*, 2003). Soil bulk density (fine earth + stony material) was determined by a specific soil core sampler. Taking advantage of the profile pits, undisturbed soil samples were taken down to the C horizon. Genetic horizons were identified and physical properties described following the standard methodology (Soil Survey Division Staff, 1993).

In the laboratory, samples were dried and passed through a 2 mm sieve. The electrical conductivity was measured by a conductivity cell, measuring the resistance of a 1:10 soil/water suspension. The pH was determined in a 1:10 soil-water suspension. Total C and N contents of the soil were measured with a C/H/N analyser (Elementar Vario EL). The $CaCO_3$ content was determined with a Scheibler's calcimeter.

Statistical analysis

To determine similarities between communities within seasons and between taxa, a cluster analysis was performed using the Unweighted Pair Group Method with Arithmetic mean (UPGMA) linking of Percent similarity index (PSI) from frequency data. Cluster analysis is an exploratory data tool widely used to identify homogeneous subgroups of cases in a population. Its object is to sort cases into groups, or clusters, so as to minimize within-group variation and maximize between-group variation (Quinn & Keough, 2002).

We used the Canonical Correspondence Analysis (CCA) to evaluate the relationship between main taxa abundance and microhabitat (chemical and physical) variables. CCA is a direct constrained ordination technique that simultaneously relates a set of taxa to a set of environmental variables.

RESULTS AND DISCUSSION

Pedofaunistic analysis

In Tab. 1, for each locality, the different taxa sampled are listed.

Aosta Valley

The fauna of the different Aostan soil samples appears characterized by a biocoenosis made of many systematic units. In all samples, the soil community is well differentiated, with representatives of all trophic levels, i.e. numerous predators (Acari, Chilopoda, larvae of Coleoptera, Aranaeidae, Pseudoscorpiones, etc.) and detritiphagous/phytophagous species (Acari, Collembola, Diplura, Diplopoda, etc.).

The presence of Protura has to be highlighted only in the locations of Bf and Bv; Diplura and Chilopoda, however, are missing, respectively, at Pb and Ro. The Pseudoscorpiones are present in all four sampling sites.

The QBS index obtained permits to place the soils considered in class 6, except for the location Pb_1 in class 5, due to the lack of Protura and/or euedaphic Coleoptera, and Bf and Bv in both seasons in class 7, the highest class, due to the presence of many euedaphic taxa making their score higher than 200.

The pedofauna of the different samples has many euedaphic groups and in the two sites of Bf and Bv also some Protura are reported. In the soils of Pb and Ro even if no Protura are found, there are adults of Coleoptera well adapted to the edaphic life. Moreover, in both cases the communities show Collembola specimens belonging to the family Onychiuridae. However, while in the site of Ro there are Diplura and Diplopoda with a high degree of adaptation to the soil, in the site of Pb the former are missing in autumn and there are only Diplopoda with a low level of edaphic adaptation.

Piedmont

The arthropod fauna of the different Piedmontese soil samples, similarly to the Aostan sites, appears well balanced and characterized by a rich biocoenosis. The community is well differentiated, with representatives from all trophic levels, with many predators (Acari, Chilopoda, larvae of Coleoptera, Aranaeidae, Pseudoscorpiones, etc.) and detritivorous/phytophagous species (Acari, Collembola, Diplura, Protura, etc.).

The pedofauna of the different samples shows many euedaphic groups, including key groups with high EMI values. The presence of particularly important taxa, sensitive to changes of various origins, such as Protura, Diplura, Chilopoda, and Pseudoscorpiones must be pointed out (Casarini *et al.*, 1990; Gardi *et al.*, 2002). A systematic group playing a significant role, and reported in all locations, is that of Collembola Onychiuridae (Parisi, 2001).

The application of the QBS index places all the soils considered in class 6, a characteristic of more complex communities of microarthropods that are better adapted to the edaphic life (Parisi, 2001).

A quick look at the various edaphic populations shows that, within the Piedmontese sites, Sc_1 has both a total number of taxa and a relative abundance significantly lower than the other three sites in Piedmont and in the Aosta Valley in general.

In particular, looking with more detail in the fauna of Sc, there is a lack of Collembola Neelidae and Neanuridae, of Diplura Japigidae, and edaphobic Coleoptera, all groups more or less present in the soil of the other sites; moreover, within the taxa with a high adaptation to subterranean life, there are only two specimens of Diplopoda in autumn, a specimen of Crustacea Isopoda in autumn and a single specimen of Pauropoda in both

Tab. 1 - List of the taxonomic categories of the sampled arthropods and of the sampled sites ($_1$=spring, $_2$=autumn).

		Sc_1	Ms_1	Bc_1	Ac_1	Bf_1	Bv_1	Pb_1	Ro_1	Sc_2	Ms_2	Bc_2	Ac_2	Bf_2	Bv_2	Pb_2	Ro_2
ACARI	Oribatidae	302	680	1267	906	839	2075	178	1162	373	3105	2205	1340	751	2467	511	2076
	other Acari	61	304	875	663	73	220	252	198	154	821	1126	693	95	425	352	248
OPILIONES		0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
COLLEMBOLA	Entomobriidae	4	41	210	574	74	88	135	23	66	404	246	582	74	84	172	51
	Isotomidae	3	71	392	349	60	114	74	124	160	233	428	395	87	120	139	316
	Sminthuridae	0	0	0	31	3	0	0	27	1	1	0	44	0	2	0	27
	Poduridae	6	10	121	0	31	0	103	161	19	35	150	0	15	594	298	823
	Neanuridae	0	2	263	22	0	0	0	0	0	5	285	51	0	0	0	0
	Onichiuridae	10	0	314	206	7	45	14	58	28	15	354	248	23	55	16	34
	Neelidae	0	0	0	0	1	0	1	2	0	1	3	0	0	1	0	1
DIPTERA	larvae	3	2	8	1	16	10	12	0	8	5	0	3	10	8	3	21
COLEOPTERA	winged adults	1	10	5	10	6	4	17	8	3	27	17	10	6	26	14	24
	larvae	6	8	11	11	15	51	2	9	17	25	39	6	9	31	11	10
	euedaphic forms	0	0	7	0	4	0	0	29	0	0	2	0	4	3	5	11
	Staphylinidae	2	11	6	7	2	34	1	50	8	26	3	7	27	21	29	49
PROTURA		1	3	33	26	5	56	0	0	2	2	63	27	10	58	0	0
DIPLURA	Japigidae	0	3	0	0	1	1	1	3	0	0	0	0	0	2	0	1
	Campodeidae	1	1	0	15	0	26	3	4	0	0	15	15	5	43	0	4
HYMENOPTERA	winged	71	12	8	11	0	2	0	5	0	16	4	10	13	13	11	28
	larvae	1	0	22	0	0	0	2	0	3	14	14	0	0	0	0	0
	wingless or brachipterous	0	0	9	3	0	0	0	5	0	0	3	1	1	0	0	4
	winged Formicidae	200	0	0	2	11	0	0	0	0	0	0	1	15	5	11	31
	worker Formicidae	0	11	11	0	12	0	5	16	0	35	1	0	1	0	7	66
PSOCOPTERA		0	2	9	4	0	0	0	3	0	3	3	5	0	0	7	4
THYSANOPTERA		3	1	5	3	0	3	3	3	2	2	7	3	5	6	2	4
HEMIPTERA	adult Leafhoppers	0	0	0	0	0	0	16	0	0	0	0	0	5	0	3	27
	juvenile Leafhoppers	0	13	1	12	9	9	33	2	1	35	14	14	7	11	32	7

		Sc_1	Ms_1	Bc_1	Ac_1	Bf_1	Bv_1	Pb_1	Ro_1	Sc_2	Ms_2	Bc_2	Ac_2	Bf_2	Bv_2	Pb_2	Ro_2
	others	0	3	0	0	0	0	0	0	1	0	0	13	0	2	0	0
MEGALOPTERA	larvae	7	36	56	1	0	3	18	0	17	79	68	52	92	9	18	92
DERMAPTERA		0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
PSEUDOSCORPIONIDA		0	0	0	1	3	2	1	24	2	0	0	3	5	9	2	4
CHILOPODA		0	10	0	8	0	1	1	15	4	11	5	7	1	3	1	1
DIPLOPODA		0	2	0	0	0	1	2	3	2	5	0	0	0	6	3	4
ISOPODA		0	1	0	1	3	1	10	12	1	0	0	0	3	3	0	6
PAUROPODA		1	6	121	11	15	4	0	2	1	18	156	306	129	1	0	0
SYMPHYLA		8	4	15	0	3	5	10	45	18	15	47	71	5	9	1	111
ARANEAE		0	4	2	15	3	6	16	7	1	4	1	0	3	16	2	4
QBS		**156**	**198**	**168**	**188**	**196**	**213**	**177**	**198**	**197**	**169**	**178**	**197**	**217**	**237**	**158**	**198**
CLASS		**6**	**6**	**6**	**6**	**6**	**7**	**5**	**6**	**6**	**6**	**6**	**6**	**7**	**7**	**6**	**6**

seasons, while the latter reach high numbers in the other three sites (from a minimum of 6 individuals for Ms_1 to a maximum of 306 for Ac_2). At this point it is worth comparing the value given to this soil by the QBS index, which is 156 in spring and 197 in autumn, leading to the ranking of class 6. The increase of the QBS value is mainly due to the mere presence of some specimens of Protura. So a more detailed analysis of the soil fauna – i.e. also considering the abundances of the different taxa - puts more light on the relative "poverty" of the soil analyzed.

Pedologic survey

In the profiles sampled in the Aosta Valley (Tab. 2), the development of organo-mineral horizons of different thickness is evident, ranging from a minimum of 5-8 cm, respectively at Bf and Bv, to a maximum of 30 cm in Pb. The thickness of organic horizons (O) (data not shown) ranged from 1.2 cm at Bf to 6.5 cm at Bv. In all sites it was possible to identify organic horizons with different degrees of alteration, with the presence of Oi, Oe and Oa horizons. We are therefore in the presence of organic matter with different degrees of alteration: from completely altered (Oa) to rather unchanged (Oi).

The soils have a highly variable depth from a minimum of about 10 cm at Bv to 70 cm at Ro. Excluding the A1 horizon of Bf, with a very low content of rocks, the % of rocks varies from 26% in the BC horizon of Bv to 65 in the C horizon of Pb. Regarding the soil reaction, the pH varies from minimum values of 5.0-5.6 in the surface horizons (A) of Ro and Bv to maximum values of 8.2 - 8.3 in the BC and C horizons of Bf and Pb. In these horizons the % of $CaCO_3$ is equal to 36.7 and 17.4, respectively. The organic

Tab. 2 - Results of the pedologic analysis of the Aostan sites.

Site	horizon	depth	rocks	pH	CE	TOC	N	C/N	$CaCO_3$
		cm	%		μScm^{-1}	%	%		%
Ro	A	0-7	35	5.0	119.3	4.47	0.22	20.5	absent
	Bw	7-40	58	5.9	80.6	2.23	0.14	15.5	absent
	BC	40-70+	43	6.2	62.7	1.84	0.07	24.6	absent
Bf	A1	0-2/5	1	7.8	311	7.92	0.46	17.2	8.26
	A2	2/5-8	27	7.7	192	1.97	0.18	10.9	18.24
	AB	8-15	28	8.0	152.3	1.47	0.16	9.2	27.06
	BC	15-35+	29	8.2	110.2	0.30	0.09	3.3	36.72
Bv	A	0-5	28	5.6	196.4	8.56	0.39	21.9	1.02
	BC	5-10+	26	6.9	178.4	3.66	0.19	19.3	1.02
Pb	A1	0-10	34	7.9	167.7	2.81	0.19	14.8	6.48
	A2	10-30	33	8.1	147.2	2.61	0.18	14.5	10.26
	AB	30-40	38	7.9	141.8	1.57	0.19	8.3	12.36
	BC	40-50	47	8.1	151.7	1.88	0.20	9.4	14.46
	C	50-60+	65	8.3	129.4	1.52	0.14	11.0	17.40

carbon concentration decreases with depth in all soils, with a minimum of 0.3% at Bf (BC horizon) and a maximum of 7.9% always at Bf (A horizon). The C/N ratio is always quite high, with values in the superficial organo-mineral horizons (A) reaching even 20.5 and 21.9, respectively in Ro and Bv, thus showing a low organic matter mineralization. The total nitrogen decreases with the depth in all soils, except for Pb, where it remains fairly constant in all horizons (0.18-0.20%).

According to the Référentiel Pédologique (AFES, 1995) the humus forms of the examined soil were classified. The dominant form is the Dysmoder, with the exception of Bf, in which a type of humus Eumoder was identified.

With regard to restrictions in the use of these soils, the reduced thickness at Bf and Bv and the abundance of rocks at Ro and Pb must be highlighted. The stock of total organic carbon (TOC) is good in all soils, with lower values in the profile open at Pb.

In the profiles sampled in Piedmont (Tab. 3), the development of organo-mineral horizons of different thickness must be pointed out, from a minimum of 2-5 cm in Ms to a maximum of 15 cm in Sc. The thickness of organic horizons (O) (data not shown) varies from 3.5 cm at Ac to about 6 cm at Sc. In all sites it was possible to identify organic horizons with different degrees of alteration, with the presence of Oi, Oe and Oa horizons. Only at Sc and Bc there is the entire sequence of organic horizons, while at Ms and Ac the presence of an Oa horizon was not found.

Tab. 3 - Results of the pedologic analysis of the Piedmontese sites.

Site	horizon	depth	rocks	pH	CE	TOC	N	C/N	$CaCO_3$
		cm	%		μScm^{-1}	%	%		%
Ms	OA	0-2/5	3	-	-	7.16	0.39	18.1	absent
	E	2/5-2/10	7	4.7	16.6	7.14	0.40	17.8	absent
	Bh	2/10-20/25	18	5.0	29.3	4.38	0.27	16.4	absent
	BC	20/25-35	26	5.0	24.3	1.65	0.13	13.1	absent
	C	35-50+	7	4.7	23.3	0.30	0.03	8.9	absent
Sc	A1	0-7	8	4.5	247.0	7.18	0.50	14.4	absent
	A2	7-15	7	4.7	170.6	4.97	0.39	12.7	absent
	AB	15-30	18	4.7	115.4	5.01	0.38	13.2	absent
	Bw	30-55	22	5.0	58.0	3.07	0.21	14.9	absent
	BC1	55-65	15	4.9	49.4	2.47	0.17	14.1	absent
	BC2	65-90+	10	5.2	343.0	1.78	0.12	15.2	absent
Bc	OA	0-3	9	-	-	28.60	1.40	20.5	absent
	A	3-8/10	17	-	-	15.31	0.96	16.0	absent
	AB	8/10-15/20	13	4.3	57.9	6.23	0.38	16.4	absent
	Bw	15/20-45	18	4.6	90.3	4.53	0.26	17.6	absent
	BC	45/70+	26	4.9	34.1	2.50	0.12	20.8	absent
Ac	A	0-5/8	11	4.6	101.6	6.60	0.34	19.4	traces
	Bw1	5/8-30/40	8	6.8	62.4	2.33	0.11	21.2	traces
	Bw2	30/40-55/60	11	7.2	51.6	1.83	0.10	18.3	traces
	BC	55/60-80+	13	6.9	30.6	1.18	0.09	13.1	traces

These soils have a variable depth, but always more than 50 cm, with peaks that may exceed the metre (Sc). The content in rocks varies from a minimum of 3% (in the A horizon of Ms) to a maximum of 26% in the deep horizons of Bc and Ms. The pH is generally from sub-acid to acid at the surface and it gets sub-acid with the increase of depth. Only at Ac there is a neutral pH depending on the presence of $CaCO_3$.

The organic carbon concentration decreases with depth in all soils, with a minimum of 0.3% at Ms (C horizon) and a maximum of 29% in the OA horizon at Bc. The C/N ratio is always quite high, with values in superficial organo-mineral horizons (A) even exceeding 20, thus showing a reduced mineralization of organic matter. The total nitrogen decreases with the depth in all soils and almost perfectly follows the trend of TOC (correlation coefficient $r=0.98$, $p <0.01$).

The humus forms were classified according to the Référentiel Pédologique (AFES, 1995). This classification shows the presence of an Amphimull humus type at Sc and Bc, while the humus form characteristic of Ms is the Hemimoder. Finally, the soil at Ac has been defined Oligomull.

The soil depth is from good to high, the presence of rocks is always pretty low, and the good amount of TOC and nitrogen of these soils make them pretty fertile.

The values of temperature and relative humidity of each soil sample collected for the pedofaunistic analysis are given in Tab. 4.

Tab. 4 - Temperature and RH values of the pedofaunistic soil samples.

	T (°C)	RH (%)
Sc_1	12.1	32.3
Ms_1	13.3	24.4
Bc_1	11.2	35.3
Ac_1	11.4	27.3
Bf_1	12.2	23.3
Bv_1	12.7	37.4
Pb_1	16.0	20.0
Ro_1	13.4	31.7
Sc_2	14.2	21.4
Ms_2	16.9	35.3
Bc_2	13.9	50.7
Ac_2	13.5	44.2
Bf_2	9.4	24.9
Bv_2	9.1	34.2
Pb_2	12.1	30.4
Ro_2	9.5	38.9

Statistical analysis

The Cluster analysis indicated that taxa composition and abundance were similar between Spring and Autumn in all areas (PSI = 73.9-89.5%) except at SC_1 (PSI = 53.4) (Fig. 2).

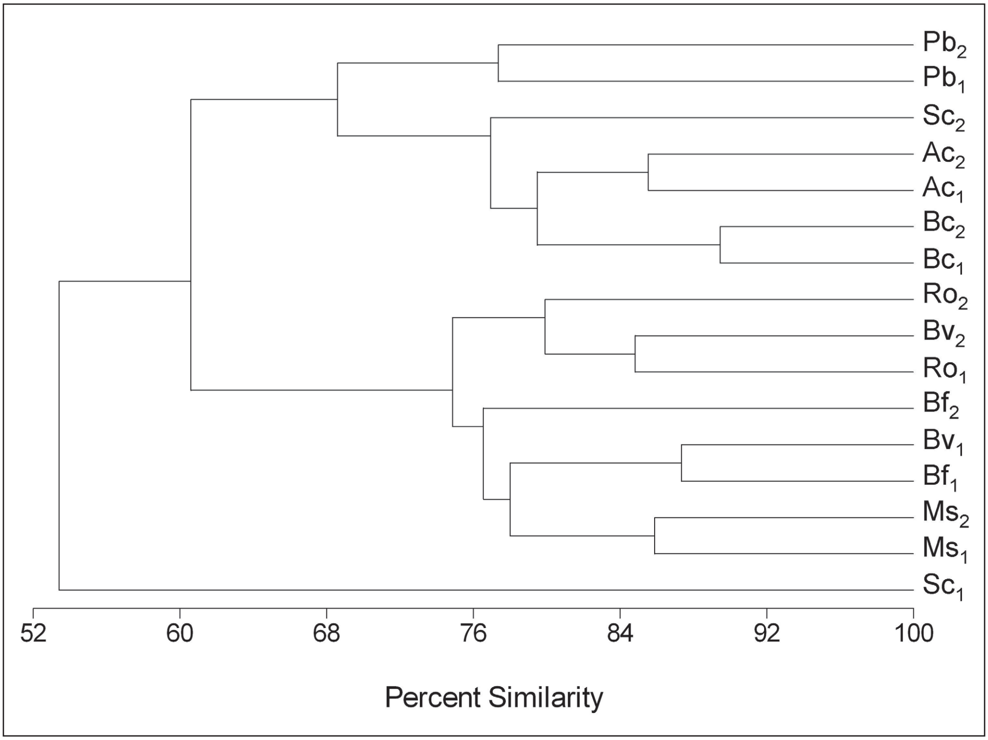

Fig. 2 - Cluster analysis of the soil populations.

The Cluster analysis using the frequency of taxa, produced two major groupings, the first one composed of the areas Pb, Ac, Bc and $Sc_{2,}$ the second one of Ro, Bv, Bf, Ms, with Sc_1 as an outgroup.

The CCA analysis (Figs. 3 and 4) show a significant difference with regard to temperature and soil humidity. In spring, the temperature affects more the presence of certain taxa than in autumn, when the humidity assumes a greater importance than in the spring.

The taxa that prefer warmer temperatures in spring are Pseudoscorpiones, Symphyla, Coleoptera, Diplura and Oribatida, while Onychiuridae, Protura and Pauropoda are taxa that seem to colonize cooler environments.

As for humidity, the taxa that seem to prefer more humid soils in autumn are in the order Onychiuridae, Pauropoda, Protura, Symphyla, Coleoptera and Oribatida, while Diplura and Pseudoscorpiones seem to prefer drier environments.

The other physical and chemical parameters are of similar importance in the two periods.

Tha taxa that prefer high values of C and N (i.e. high values of organic matter) are Onychiuridae, Pauropoda, Protura; the Oribatida seem almost indifferent to variations of C and N, while the Pseudoscorpiones seem also able to colonize soils with lower contents of organic matter.

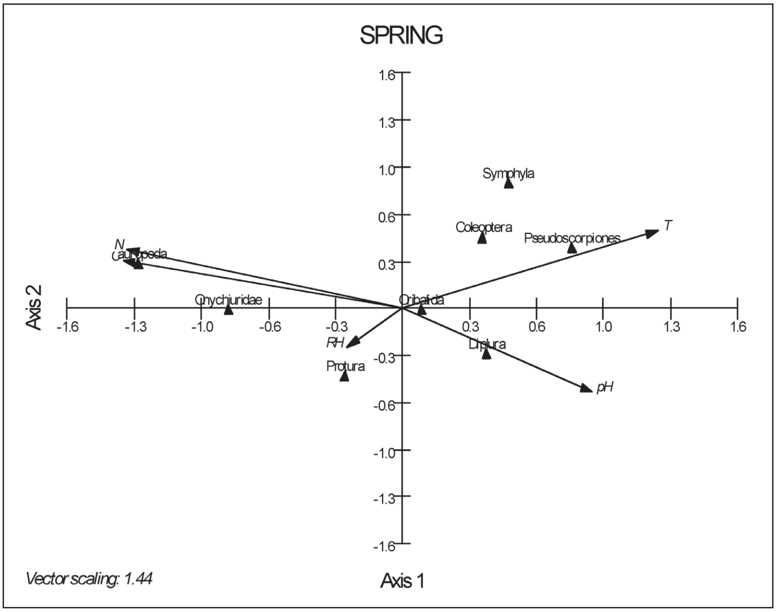

Fig. 3 - Canonical Correspondence Analysis of the taxa collected in spring and of the physico-chemical parameters of the investigated soils.

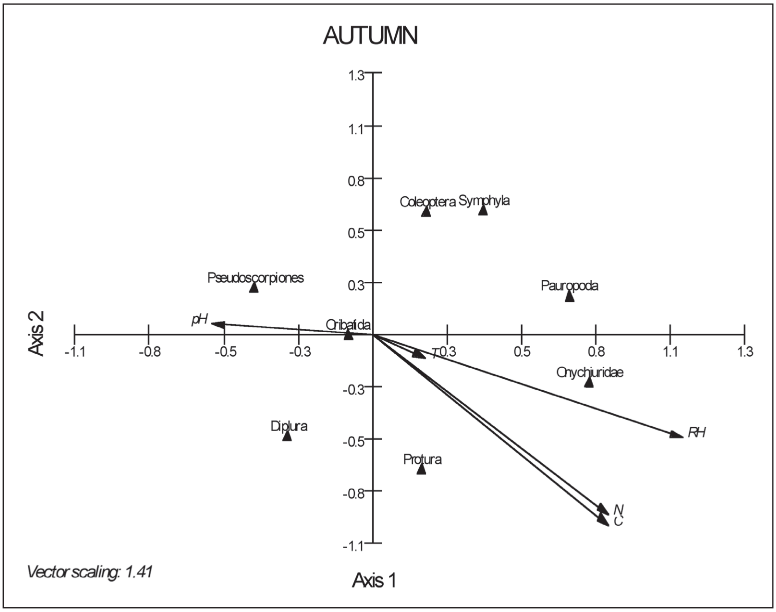

Fig. 4 - Canonical Correspondence Analysis of the taxa collected in autumn and of the physico-chemical parameters of the investigated soils.

Regarding pH, the taxa that prefer higher values are Pseudoscorpiones, Diplura, Symphyla, Coleoptera, Oribatida and Diplura, while Pauropoda and Onychiuridae seem to prefer environments with a lower pH.

CONCLUSIONS

The application of the QBS index on the sampled soils leads to the conclusion that the edaphic communities living there are fully differentiated and balanced, as they are characterized by all trophic levels and the presence of all the key taxa. A more detailed study that takes into account the abundance of the different taxa, shows that in the site of Scarliccio in spring, the soil fauna is substantially poorer than the other sites, which places it as the outgroup in the cluster analysis. The remaining sites show instead complex microarthropod communities well adapted to the edaphic life in both seasons, confirming a good general state of health of the soil of these Scots pine forests.

According to the results of the pedofaunistic survey conducted, to assess the biological quality of soils it is important also to consider the abundances of the different taxa found, as some authors suggested with the application of quali-quantitative indicators (Nizzoli *et al.*, 2004).

Among the soil parameters that may affect the soil fauna, besides the chemical and physical parameters considered, the evaluation of the depth of organo-mineral horizons (A horizons) – where macroinvertebrates live – could be important and worthy of further investigation, keeping in consideration the fact that the QBS method limits the survey only to the superficial layer of 10 cm of depth.

A positive correlation between the value of QBS and stoniness of the soil has already been observed in alpine soils of the Chiavenna Valley (Comolli & Ballabio, unpublished data). Soils with a greater stoniness and a greater disturbance by erosion and cryoturbation, are characterized by more developed microarthropod communities and a higher QBS index. This could have a positive effect on the airing of these soils, whose quality may be affected importantly by anoxia for long periods of the year because of the abundance of water at the time of thaw.

By contrast, in more developed soils, with thicker A horizons and a lower content of rocks, the QBS index seems to be generally lower (D'Amico *et al.*, 2009), as these soils tend to be more asphyxial and dry because of compaction and abundance of hydrophobic organic substances in superficial horizons. This may hold true for some of the sites investigated, including Pb and Sc, but more investigations in this regard would be needed.

Integrated pedologic-pedofaunistic studies, basic to improve the knowledge of the subterranean environment, so complex as well as poorly investigated, require more human and economic resources from the institutions and researchers involved, so to create a database on which to draw in the biological quality assessment of different environmental realities.

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RIASSUNTO

Indagine pedofaunistica e pedologica in pinete a pino silvestre in Valle d'Aosta e Piemonte.

Attualmente per meglio valutare gli effetti sull'ambiente delle attività antropiche, ma non solo, vengono sempre più sovente impiegati anche indicatori biologici che si basano sulla sensibilità, più o meno spiccata, di alcuni gruppi animali, prevalentemente artropodi, a variazioni ambientali. Molti studi sono stati condotti a tal proposito sugli ambienti acquatici mentre solo in tempi relativamente recenti l'attenzione di alcuni ricercatori si è rivolta anche al suolo iniziando promettenti studi volti non solamente a conoscere più dettegliatamente la composizione della pedofauna ma anche ad osservarne i mutamenti ritenuti importanti indici di cambiamento ambientale. Attualmente tra i diversi indici proposti quello più utilizzato, soprattutto per la sua praticità e relativa rapidità di applicazione, è l'indice di Qualità Biologica del Suolo (QBS) che permette, sommando gli Indici Ecomorfologici (EMI) attribuiti ai diversi taxa trovati nei campioni di suolo, di esprimere un giudizio sullo stato di salute del suolo ed eventualmente valutare variazioni rispetto ad indagini precedenti. Il presente studio si propone di esaminare l'artropodofauna in suoli di pinete a pino silvestre in Valle d'Aosta e in Piemonte.

A tale scopo sono stati scelti, in Valle d'Aosta, quattro siti: Bois de Feisouilles (Bf), a Morgex; Bois de Vorpeiller (Bv) e Petit Bruson (Pb) a St. Denis e Rouvere (Ro) a Challand-St-Anselme, altrettanti in Piemonte: Monte Solivo (Ms) a Borgo Ticino in provincia di Novara; Scarliccio (Sc) a Santa Maria Maggiore, Bosco della Colma (Bc) a Toceno e Alpe Ciona (Ac) a Trasquera tutti in provincia di Verbano-Cusio-Ossola (Fig. 1). In ogni sito nella tarda primavera e all'inizio dell'autunno del 2005 sono stati prelevati tre campioni di suolo, quando possibile di un dm^3 ciascuno, accuratamente scelti per poter poi ottenere un unico campione rappresentativo. In laboratorio dai diversi campioni sono stati estratti, mediante l'estrattore Berlese-Tullgren, gli artropodi presenti, conservati in alcol 70°, e, per essiccamento, l'acqua ottenendo così l'umidità del suolo. Gli animali estratti sono quindi stati classificati (Tab. 1) e con l'attribuzione a ciascuna famiglia degli indici EMI è stato possibile valutare la qualità dei diversi suoli applicando il metodo QBS.

Sebbene l'esame della pedofauna si sia limitato all'orizzonte organo minerale A, si è ritenuto utile poter disporre di più precise valutazioni pedologiche dei suoli esaminati. Nei diversi siti sono state perciò effettuate indagini pedologiche di maggiore dettaglio, con l'individuazione degli orizzonti genetici. I campioni di suolo sono stati prelevati in ciascun orizzonte e successivamente essiccati e setacciati a 2mm per la determinazione dello scheletro. Sulla terra fine (<2mm) è stata effettuata la determinazione di pH, conducibilità elettrica (CE), contenuto di carbonio organico (TOC), azoto totale (TN) e $CaCO_3$ (Tabb. 2 e 3).

I dati, sia faunistici sia pedologici, sono poi stati sottoposti ad analisi statistica mediante la Cluster analysis e la Canonical Correspondence Analysis (CCA) per evidenziare le affinità qualitative tra i suoli dei diversi siti e l'influenza dei diversi fattori chimico-fisici sulle biocenosi pedofaunistiche presenti nei due periodi di indagine.

I campioni di suolo raccolti in Valle d'Aosta appaiono caratterizzati da biocenosi ben strutturate, sono infatti presenti specie caratteristiche dei diversi livelli trofici quali fitofagi e detritivori oltre a numerose specie di predatori. I suoli considerati si collocano prevalentemente in classe 6, tranne i campioni raccolti nei due periodi a Bf e Bv, in classe 7, la massima prevista dal metodo. Fa eccezione il campione di suolo raccolto in primavera in località Pb per la mancanza di Proturi e Coleotteri edafobi. I campioni raccolti nelle località piemontesi non si discostano molto per ricchezza di specie e per l'equilibrata biocenosi da quelli valdostani in quanto sono ben rappresentati i diversi livelli trofici e si collocano tutti in classe 6. Qualche perplessità sull'affidabilità del metodo sorge analizzando il campione raccolto a Sc, dove risultano infatti assenti alcune importanti famiglie di Collemboli e di Coleotteri edafobi determinando, soprattutto in primavera, un notevole abbassamento del valore di QBS, ma la presenza di alcuni esemplari di Proturi fa sì che anche in questo caso si raggiunga la classe 6.

I suoli oggetto di studio in Valle d'Aosta risultano caratterizzati dallo sviluppo di orizzonti organo-minerali (A) di differente potenza, da un minimo di 5-8 cm rispettivamente a Bf e Bv a un massimo di 30 cm a Pb. In tutti i siti è stato possibile individuare orizzonti organici a differente grado di alterazione, con la presenza di orizzonti Oi, Oe ed Oa.

I suoli hanno potenze molto variabili da un minimo di circa 10 cm a Bv a un massimo di 70 cm a Ro. Escluso l'orizzonte A1 a Bf, con bassissimo contenuto di scheletro, la percentuale di scheletro varia dal 26 nell'orizzonte BC a Bv al 65 dell'orizzonte C a Pb. Per quanto concerne la reazione del suolo, il pH varia da valori minimi di 5.0-5.6 negli orizzonti superficiali (A) a Ro e Bv a valori massimi di 8.2–8.3 negli orizzonti BC e C a Bf e Pb. In tali orizzonti la percentuale di $CaCO_3$ è pari rispettivamente a 36.7 e 17.4. La concentrazione di carbonio organico (TOC) decresce con la profondità in tutti i suoli, con un valore minimo di 0.3% a Bf (orizzonte BC) ed un massimo di 7.9% sempre a Bf (orizzonte A). Il rapporto C/N è sempre piuttosto elevato, con valori negli orizzonti organo-minerali (A) di superficie pari anche a 20.5 e 21.9, rispettivamente a Ro e Bv, ad evidenziare una ridotta mineralizzazione della sostanza organica. La dotazione di azoto diminuisce con la profondità in tutti i suoli, ad eccezione di quelli raccolti a Pb, dove si mantiene piuttosto costante in tutti gli orizzonti (0.18-0.20%). Per quanto concerne le limitazioni d'uso di questi suoli, si evidenzia la ridotta potenza a Bf e Bv e l'abbondanza di scheletro a Ro e Pb. La dotazione di sostanza organica è buona in tutti i suoli, con valori inferiori nel profilo aperto a Pb.

Per quanto concerne i siti piemontesi, si evidenzia lo sviluppo di orizzonti organo-minerali di differente potenza, da un minimo di 2-5 cm a Ms ed un massimo di 15 cm a Sc. In tutti i siti è stato possibile individuare orizzonti organici a differente grado di alterazione, con la presenza di orizzonti Oi, Oe ed Oa. Soltanto a Sc e Bc vi è però l'intera sequenza di orizzonti organici, mentre a Ms e Ac non si riscontra la presenza di un orizzonte Oa.

I suoli hanno potenze variabili sempre superiori ai 50 cm, con massimi anche superiori al metro (Sc). Il contenuto in scheletro varia da un minimo del 3% (nell'orizzonte A a Ms) ad un massimo di 26% negli orizzonti profondi a Bc e Ms. Il pH è generalmente da subacido ad acido in superficie e diventa subacido al'aumentare della profondità. Solo a Ac si osservano pH neutri in relazione alla presenza di $CaCO_3$.

La concentrazione di carbonio organico (TOC) decresce con la profondità in tutti i suoli, con un valore minimo di 0.3% a Ms (orizzonte C) ed un massimo di 29% nell'orizzonte OA a Bc. Il rapporto C/N è sempre piuttosto elevato, con valori negli orizzonti organo-minerali (A) di superficie pari anche superiori a 20, ad evidenziare una ridotta mineralizzazione della sostanza organica. La dotazione di azoto diminuisce con la profondità in tutti i suoli e segue quasi perfettamente l'andamento del carbonio organico (coefficiente di correlazione $r=0.98$, $p<0.01$). La profondità del suolo, da buona ad elevata, la presenza di scheletro, sempre piuttosto contenuta, e la buona dotazione di carbonio organico ed azoto rendono la fertilità di questi suoli piuttosto elevata.

La Cluster analysis (Fig. 2) ha chiaramente separato i campioni, riunendoli per similitudini pedofaunistiche, in due gruppi: il primo formato dai campioni raccolti a Pb, Ac, Bc più quello autunnale di Sc, il secondo comprendente i campioni provenienti da Ro, Bv, Bf e Ms; per quanto poc'anzi detto rimane fuori dai gruppi il campione raccolto in primavera a Scarliccio. L'analisi CCA ha invece dimostrato, come risulta chiaro dai grafici (Figg. 3 e 4), la diversa sensibilità dei numerosi taxa ai parametri chimico-fisici del suolo, in particolare si può dire che per il maggior numero di taxa la temperatura più elevata ha una notevole importanza in primavera mentre in autunno risulta più importante un'elevata umidità del suolo. Valori alti di C e N favoriscono lo sviluppo di Onychiuridae, Pauropoda, Protura mentre valori alti di pH favoriscono la presenza di Pseudoscorpionida, Diplura, Symphyla, Coleoptera, Oribatida e Diplura.

L'indice QBS fornisce una buona base per la valutazione della qualità del suolo ma stimola anche alcune riflessioni suggerite soprattutto dall'attento confronto dei risultati, in particolare quelli ottenuti dai campioni raccolti a Scarliccio; appare infatti evidente che anche il numero degli esemplari trovati per ciascun taxon avrebbe potuto determinare una diversa classificazione dei campioni; a tal proposito alcuni autori suggeriscono un'analisi quali-quantitativa della pedofana. Inoltre dalle osservazioni dei vari orizzonti raccolti si evidenzia l'opportunità sia di esaminare in tutta la sua potenza l'orizzonte A, quello dove la pedofauna è più presente, e non soffermarsi ai primi 10 cm previsti dal metodo, sia di valutare attentamente la presenza dello scheletro che, intervenendo nella compattazione del suolo, può determinare variazioni nelle percentuali di umidità e di aria presenti, fattori che influenzano direttamente le popolazioni pedofaunistiche. Si rende quindi indispensabile la stretta collaborazione tra pedologi e ricercatori con specifiche competenze pedofaunistiche per migliorare le conoscenze della qualità del suolo e predisporre, con tutti i dati disponibili, un database, importante strumento da cui attingere indispensabili informazioni.

RÉSUMÉ

Enquête pédofaunistique et pédologique en pinèdes à pin sylvestre en Vallée d'Aoste et Piémont.

Actuellement, afin de mieux évaluer les effets sur l'environnement des activités anthropiques, et pas seulement, il est de plus en plus fréquent d'utiliser des indicateurs biologiques qui se basent sur la sensibilité, plus ou moins forte, de quelques groupes d'animaux, principalement arthropodes, aux variations de l'environnement. De nom-

breuses études ont été menées à ce sujet sur les milieux aquatiques, tandis que récemment l'attention des chercheurs s'est orientée aussi vers le sol, donnant lieu à des études prometteuses destinées non seulement à connaître d'une façon plus détaillée la composition de la pédofaune, mais aussi à en observer les mutations considérées comme d'importants indices du changement environnemental. Parmi les différents indices maintenant proposés, le plus utilisé, de par sa practicité et sa relative rapidité d'application, est l'indice de Qualité Biologique du Sol (QBS), qui permet, en ajoutant les Indices Éco-morphologiques (EMI) attribués aux divers taxa trouvés dans les échantillons de sol, d'exprimer un jugement sur l'état de santé du sol et éventuellement évaluer les variations par rapport à de précédents sondages. L'étude en question se propose d'examiner l'arthropodofaune en sol de pinèdes à pin sylvestre en Vallée d'Aoste et au Piémont.

Dans ce but, quatre sites ont été choisis en Vallée d'Aoste: Bois de Feisouilles (Bf), à Morgex; Bois de Vorpeiller (Bv) et Petit Bruson (Pb) à St. Denis et Rouvere (Ro) à Challand-St-Anselme, autant au Piémont: Monte Solivo (Ms) à Borgo Ticino en province de Novara; Scarliccio (Sc) à Santa Maria Maggiore, Bosco della Colma (Bc) à Toceno et Alpe Ciona (Ac) à Trasquera tous dans la province de Verbano-Cusio-Ossola (fig.1). Dans chaque site, à la fin du printemps et au début de l'automne de 2005, ont été prélevés trois échantillons de sol, quand cela était possible, d'un dm^3 chacun, soigneusement choisis pour pouvoir ensuite obtenir un seul et unique échantillon représentatif. À partir des différents échantillons, on a extrait en laboratoire, grâce à l'extracteur Berlese-Tullgren, les arthropodes présents, conservés dans de l'alcool à 70°, et par séchage, l'eau, obtenant ainsi le taux d'humidité du sol. Les animaux extraits ont été ensuite classifiés (Tab. 1) et avec l'attribution à chaque famille des indices EMI, il a été possible d'évaluer la qualité des différents sols en utilisant la méthode QBS.

Bien que l'examen de la pédofaune ait été limité à l'horizon organo-minéral A, il a été considéré utile de pouvoir disposer d'évaluations pédologiques plus précises des sols examinés. Dans les différents sites ont été alors effectuées des études pédologiques plus approfondies, avec l'identification des horizons génétiques. Les échantillons de sol ont été prélevés dans chaque horizon et par la suite séchés et tamisés à 2mm pour la détermination des éléments grossiers. Sur la terre fine (<2mm) ont été effectués la détermination du pH, la conductivité électrique (CE), le contenu de carbone organique (TOC), l'azote total (TN) et le $CaCO_3$ (Tab. 2 et 3).

Les données, soit faunistiques soit pédologiques ont ensuite fait l'objet d'une analyse statistique au moyen de la Cluster analysis et de la Canonical Correspondence Analysis (CCA) afin de mettre en évidence les affinités qualitatives entre les sols des divers sites et l'influence des multiples facteurs chimiques et physiques sur les biocénoses pédofaunistiques présentes pendant les deux périodes de l'enquête.

Les échantillons récoltés en Vallée d'Aoste semblent être particularisés par des biocénoses non structurées, car sont en effet présentes des espèces caractérisées par les différents niveaux trophiques tels que phytophages et détritivores et, en outre, beaucoup d'espèces de prédateurs. Les sols considérés se placent principalement en classe 6, sauf les échantillons prélevés dans les deux périodes à BF et Bv, en classe 7, le maximum prévu par la méthode. Seule exception, l'échantillon de sol récolté au printemps dans la localité Pb pour l'absence de Protures et Coléoptères édaphobes. Les échantillons prélevés dans les localités du Piémont sont assez similaires en termes de richesse d'espèces et d'équilibre de la biocénose à ceux valdôtains en raison de la bonne représentation des divers niveaux trophiques et se placent tous en classe 6. Quelques perplexités sur la fiabilité de la méthode ont surgi lors de l'analyse de l'échantillon récolté à Sc, où résultent absentes quelques importantes familles de Collemboles et de Coléoptères edaphobes déterminantes, surtout au printemps, une diminution considérable de la valeur de QBS, mais la présence de quelques exemplaires de Protures fait en sorte que même dans ce cas, on atteint la classe 6.

Les sols étudiés en Vallée d'Aoste sont caractérisés par un développement d'horizons organo-minéraux (A) de différentes épaisseurs, d'un minimum de 5-8 cm respectivement à Bf et Bv à un maximum de 30 cm à Pb. Dans tous les sites, il a été possible d'identifier des horizons organiques à des degrés variés d'altération, avec la présence d'horizons Oi, Oe et Oa.

Les sols ont une profondeur variable d'un minimum de 10 cm à Bv à un maximum de 70 cm à Ro. Excepté l'horizon A1 à Bf avec un bas contenu d'éléments grossiers, le pourcentage d'éléments grossiers varie de 26 dans l'horizon BC à Bv à 65 de l'horizon C a Pb. En ce qui concerne la réaction du sol, le pH varie d'un minimum de 5.0-5.6 dans les horizons superficiels (A) à Ro et Bv à un maximum de 8.2-8.3 dans les horizons BC et C à Bf et Pb. Dans ces horizons, le pourcentage de $CaCO_3$ est respectivement de 36.7 et 17.4. La concentration de carbone organique (TOC) décroit avec la profondeur dans tous les sols, avec une valeur minimum de 0.3% à Bf (horizon BC) et un maximum de 7.9% toujours à Bf (horizon A). Le rapport C/N est toujours plutôt élevé, avec des valeurs dans les horizons organo-minéraux (A) de surface de 20.5 et 21.9 respectivement à Ro et Bv, a montré une minéralisation réduite de la substance organique. La composition en azote diminue avec la profondeur dans tous les sols à l'exception de ceux récoltés à Pb, qui se maintiennent plutôt constants dans tous les horizons (0.18-0.20%). En ce qui concerne les limitations d'utilisation de ces sols, on note bien la profondeur limitée à Bf et Bv et l'abondance d'éléments grossiers à Ro et Pb. La dotation de substance organique est bonne dans tous les sols, avec des valeurs inférieures dans le profil ouvert à Pb.

En ce qui concerne les sites piémontais, on remarque le développement d'horizons organo-minéraux de différentes épaisseurs, d'un minimum de 2-5 cm à Ms à un maximum de 15 cm à Sc. Dans tous les sites, on a pu identifier des horizons organiques à degrés variés d'altération, avec la présence d'horizons Oi, Oe et Oa. Seulement à Sc et Bc on trouve la séquence complète des horizons organiques, tandis qu'à Ms et Ac on ne remarque pas la présence d'un horizon Oa.

La concentration de carbone organique (TOC) décroit avec la profondeur dans tous les sols, avec une valeur minimum de 0.3% à Ms (horizon C) et un maximum de 29% dans l'horizon Oa à Bc. Le rapport C/N est toujours plutôt élevé, avec des valeurs dans les horizons organo-minéraux (A) de surface même supérieures à 20; à remarquer, une minéralisation réduite de la substance organique. La dotation d'azote diminue avec la profondeur dans tous les sols, et suit presque parfaitement la tendance du carbone organique (coefficient de corrélation $r=0.98$, $p<0.01$). La profondeur du sol, de bonne à élevée, la présence d'éléments grossiers, toujours assez contenue, et la bonne composition en carbone organique et d'azote rendent la fertilité de ces sols plutôt élevée.

La Cluster analysis (Fig. 2) a clairement séparé les échantillons en les réunissant par similitudes pédofaunistiques, en deux groupes: le premier constitué des échantillons récoltés à Pb, Ac, Bc plus celui automnal de Sc, le second comprend les échantillons qui proviennent de Ro, Bv, Bf et Ms, selon ce qu'on vient de dire, l'échantillon récolté en printemps à Scarliccio reste en dehors des groupes. L'analyse CCA a, par contre, démontré, comme il apparaît clairement dans les graphiques (Fig. 3 et 4), la différente sensibilité des nombreux taxa aux paramètres chimiques et physiques du sol, en particulier, on peut dire que pour le plus grand nombre de taxa, la température plus élevée a une importance considérable au printemps tandis qu'en automne l'humidité du sol est plus importante.

Les valeurs élevées de C et N favorisent le développement de Onychiuridae, Pauropoda, Protura tandis que les valeurs élevées de pH favorisent la présence de Pseudoscorpiones, Diplura, Symphyla, Coleoptera, Oribatida et Diplura.

L'indice QBS nous fournit une bonne base pour l'évaluation de la qualité du sol mais génère aussi quelques réflexions surtout dues à une comparaison attentive des résultats, en particulier ceux obtenus à partir des échantillons récoltés à Scarliccio; il semble en effet évident que le nombre d'exemplaires trouvés pour chaque taxon ait pu déterminer une classification différente des échantillons; à ce sujet quelques auteurs suggèrent une analyse qualitative et quantitative de la pédofaune. En outre, à partir des observations des horizons récoltés, on remarque l'opportunité, d'une part, d'examiner dans toute sa profondeur l'horizon A, celui où la pédofaune est plus présente, en ne s'arrêtant pas au premiers 10cm prévus par la méthode, et d'autre part, d'évaluer attentivement la présence d'éléments grossiers intervenant dans la compaction du sol et déterminant la variation dans le pourcentage d'humidité et de l'air présent. Tous ces facteurs influencent directement les populations pédofaunistiques. La collaboration étroite entre pédologues et chercheurs ayant des compétences pédofaunistiques spécifiques devient alors fondamentale pour améliorer les connaissances de la qualité des sols et constituer, avec toutes les données disponibles, une base de données, instrument important à partir duquel on pourra obtenir des informations indispensables.

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