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Does changing the taxonomical resolution alter the value of soil macroinvertebrates as bioindicators of metal pollution?

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Abstract

Ecological indicators are taxa that are affected by, and indicate effects of, anthropogenic environmental stress or disturbance on ecosystems. There is evidence that some species of soil macrofauna (i.e. diameter >2 mm) constitute valuable biological indicators of certain types of soil perturbations. This study aims to determine which level of taxonomic resolution, (species, family or ecological group) is the best to identify indicator of soil disturbance. Macrofauna were sampled in a set of sites encompassing different land-use systems (e.g. forests, pastures, crops) and different levels of pollution. Indicator taxa were sought using the IndVal index proposed by Dufrêne and Legendre [Dufrêne, M., Legendre, P., 1997. Species assemblages and indicator species: the need for a flexible asymetrical approach. Ecological Monographs 67, 345–366]. This approach is based on a hierarchical typology of sites. The index value changes along the typology and decreases (increases) for generalist (specialist) faunal units (species, families or ecological groups). Of the 327 morphospecies recorded, 19 were significantly associated with a site type or a group of sites (5.8%). Similarly, species were aggregated to form 59 families among which 17 (28.8%) displayed a significant indicator value. Gathering species into 28 broad ecological assemblages led to 14 indicator groups (50%). Beyond the simple proportion of units having significant association with a given level of the site typology, the proportion of specialist and generalist groups changed dramatically when the level of taxonomic resolution was altered. At the species level 84% of the indicator units were specialist, whereas this proportion decreased to 70 and 43% when families and ecological groups were considered. Because specialist groups are the most interesting type of indicators either in terms of conservation or for management purposes we come to the conclusion that the species level is the most accurate taxonomic level in bioindication studies although it requires a high amount of labour and operator knowledge and is time-consuming.

Keywords: Bioindicators; Soil macrofauna; Metal pollution; Indicator value; Taxonomical resolution

1. Introduction

Bioindicators can be defined as a species or assemblage of species that is particularly well matched to specific features of the landscape and/or reacts to impacts and changes (Paoletti, 1999a, b; Büchs, 2003). Identifying characteristic or indicator species is important for conservation or management purposes (Büchs, 2003). Ideally, indicator species should: (a) be holistic but closely related to assessment goals, (b) show a response to a range of environmental stresses, (c) show an integrative potential in the long-term and (d) be easily measured, quantified and interpreted (Lobry de Bruyn, 1997). In the context of soil bioindicators, the latter requirement might be difficult to fulfil if indicators are sought at the species level because of the high taxonomical knowledge required and the high diversity of soil biota (Giller, 1996). This point brings up the question of determining which level of taxonomic resolution is the best to identify characteristic species of soil fauna. Does changing the taxonomical resolution alter the value of soil macroinvertebrate as bioindicators and what information is lost when broad taxonomic levels, e.g. families are used instead of species?

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In this paper, we use a data set collected in a metal contaminated area in northern France (Nahmani and Rossi, 2003) where various land-uses, either polluted or not, were investigated, e.g. grasslands, forests, cultivated lands. We searched for indicator taxa of these habitats using soil macrofauna and different taxonomic levels namely, species and families as well as ecological groups defined on the basis of their known food resources and habitat requirements. Appropriate indicators should return low variance for the mean number of individuals recorded per site and a high degree of habitat preference for the habitat considered (Perner and Malt, 2003). These requisites are met by the Indicator Value Index (IndVal) proposed by Dufrêne and Legendre (1997) which quantifies the degree to which each species fulfils the criteria of specificity (uniqueness to a particular site) and fidelity (frequency within that habitat type (McGeoch and Chown, 1998).

2. Material and methods

2.1. Site and sampling protocol

2.1.1. Sites

The survey was carried out in October 1999 in different plots located northeast of the alluvial plain of Scarpe-Escault, in northern France (Mortagne-du-Nord, Nord-Pas-de-Calais, France). In this zone, past emissions from a Zn smelter (1901–1962) resulted in considerable metal contamination of soils of the surrounding agricultural land (Balabane and van Oort, 2002; van Oort et al., 2002). Fourteen study sites distributed at increasing distance from the zinc smelter were selected (Table 1). Sites A and B, closest to the former industrial plant, were metallophyte grasslands (Dahmani-Muller et al., 2000; Schwartz et al., 2001). Sites C to E were polluted poplar plantations (Table 1). Sites F to G and J to M, ranging from 1 to 4 km from the source in the direction of dominant winds, were located in agricultural land; they included two unpolluted poplar plantations (sites F and G), an unpolluted forest (site H), two unpolluted cultivated soils (sites J and K), and two unpolluted grasslands (sites L and M). Two additional unpolluted sites were investigated. They were located in the opposite direction and comprise grassland (site N) and a forest (site I).

2.1.2. Sampling

At each site, eight soil cores distributed along two transects and taken from a depth of 15 cm, were air dried, sieved and mixed thoroughly to form a composite sample. The resulting soil samples were analysed to determine the concentrations of the pollutants Zn, Cd, Pb and Cu (NF X31-151, AFNOR, 1994). Within each sampling site, two parallel transects separated by 1 m were set up. Each transect had four sampling points spaced 2 m apart. At each sampling point, a metallic frame (25×25 cm) was inserted in the soil; the litter was then collected and its soil fauna collected using Berlese extraction after hand-sorting. The Berlese-funnels were 25 cm in diameter with a sieve mesh of 4 mm (Southwood and Henderson, 2000). Macroorganisms were extracted from the soil by two applications of a 0.2% formalin solution followed by hand-sorting. Specimens were preserved in 4% formalin. The macroorganisms were first identified at the level of morphospecies and most of them at the species level. Species were grouped into families and according to their ecological niches (food resources, habitat; Table 2).

2.2. The indicator value

2.2.1. Principle

Indicator species of each habitat type were identified using the Indicator Value (IndVal) method (Dufrêne and Legendre, 1997). The indicator value (i.e. the measure of sites and species association) is computed on the basis of the within-species abundance and occurrence comparisons. There is no between-species comparison.

Table 1
Vegetation type, pollution status and soil metal content of 14 sites located within an area contaminated by past emissions from a Zn smelter (1901–1962)

Site	Vegetation type	Pollution status	Zn content (ppm)	Pb content (ppm)	Cd content (ppm)
A	Metallophyte grassland	Highly polluted	17,956	4720	79
B	Metallophyte grassland	Highly polluted	35,116	8271	190
C	Poplar plantation	Polluted	1112	616	12
D	Poplar plantation	Polluted	3499	401	26
E	Poplar plantation	Polluted	>1000	>400	>10
F	Poplar plantation	Unpolluted	286	73	2
G	Poplar plantation	Unpolluted	104	63	<1
H	Forest	Unpolluted	44	75	<1
I	Forest	Unpolluted	101	115	2
J	Field	Unpolluted	241	58	1.8
K	Field	Unpolluted	241	58	1.78
L	Grassland	Unpolluted	–	–	–
M	Grassland	Unpolluted	300	85	<1
N	Grassland	Unpolluted	77	40	<1

Table 2
Families and ecological groups of soil macrofauna in 14 polluted and unpolluted sites in northern France

Ecological groups	Families/sub-families
Araneida*	Agelenidae*
	Anyphaenidae
	Araneidae
	Dictynidae
	Linyphiidae
	Lycosidae
	Palpimanidae
	Pholcidae
	Salticidae
	Thomisidae
	Uloboridae
	Zodariidae
Opiliones	Opilionidae
Phytophagous Coleoptera*	Chrysomelidae
	Cucurlionidae*
Phytophagous Coleoptera larvae	Curculionidae larvae
	Scarabaeidae larvae
Zoophagous Coleoptera*	Carabidae
	Coccinellidae
	Hydrophidae
	Scydmaenidae
	Silphidae
	Staphylinidae*
Zoophagous Coleoptera larvae*	Carabidae larvae
	Staphylinidae larvae*
Rhyzophagous Coleoptera larvae*	Rutelidae larvae*
Phytophagous & Zoophagous Coleoptera larvae	Elateridae larvae
Coprophagous Coleoptera	Scarabaeidae
	Elateridae
	Dermestidae larvae
	Lampyridae larvae
Chilopoda*	Geophilidae*
	Lithobiidae*
	Scolopendridae*
Diplopoda*	Polydesmidae*
	Craspedosomidae
	Iulidae
Epigeic earthworm*	Lumbricidae*
Endogeic earthworm*	
Anecic earthworm	
Enchytreidae*	Enchytraeidae*
Ant	Formicidae Formicinae
	Formicidae Myrmicinae
Gastropoda*	Arionidae*
	Clausiliidae*
	Valloniidae*
Dermaptera*	Forficulidae*
Isopoda*	Philoscidae*
Trichoptera*	Limnephilidae larvae*
Diptera larvae	

* indicates taxa with a significant indicator value.

The first step of the analysis is obtaining a site typology. Various strategies can be adopted, independently of the Indicator Value method itself (see Dufrêne and Legendre, 1997). Secondly, the indicator species of one group of the site typology are identified. Indicator species are species mostly present in one of the groups forming the typology, while being also present in the majority of the sites belonging to that group. The latter component refers to the species frequency within the site group.

For each species i in each site group j the term A_{ij} is computed as follows:

$$A_{ij} = N\text{individuals}_{ij}/N\text{individuals}_{i}. \tag{1}$$

A_{ij} is the mean abundance of the species i in the group of sites j and measures the *specificity* of the species i to the group of sites j. $N\text{individuals}_{ij}$ is the mean number of individuals of species i across sites of group j. $N\text{individuals}_{i}$ is the sum of the mean numbers of individuals of species i over all groups. A_{ij} is maximum when the species i is only present in the site group j.

A second term, B_{ij}, is also computed for each species i in each site group j. The formula is:

$$B_{ij} = N\text{sites}_{ij}/N\text{sites}_{.j}. \tag{2}$$

B_{ij} is the relative frequency of occurrence of the species i in the sites of group j. It is a measure of *fidelity*. $N\text{sites}_{ij}$ is the number of sites in the site group j, where the species i is present and the $N\text{sites}_{.j}$ is the total number of sites in that site group. B_{ij} is maximum when the species i is present in all the sites of the site group j. The indicator value is computed by combining the specificity (A_{ij}) and the fidelity (B_{ij}) terms by multiplication because they correspond to independent information about species pattern. A final multiplication by 100 leads to a percentage.

$$\text{IndVal}_{ij} = A_{ij} \times B_{ij} \times 100 \tag{3}$$

For a given site typology, the indicator value of a species i is the largest value of IndVal_{ij} observed over all groups in that typology. $\text{IndVal}_{i} = \max(\text{IndVal}_{ij})$. The indicator value is maximum (i.e. 100%), when all individuals are found in a single group of sites and when the species occurs in all the sites forming that group.

The method can be used in the case of a hierarchical typology and the indicator value is computed for all the levels (i.e. site groupings) of the site typology. The indicator value is assumed to change along the hierarchical typology. As indicated by Dufrêne and Legendre (1997), the indicator value is high (low) and decreases (increases) for generalist (specialist) species when the number of clusters increases. The indicator value also allows identifying species typical of intermediate level of the clustering history. Testing for statistical significance is achieved by randomly reallocating sites among site groups (Dufrêne and Legendre, 1997) and recomputing the index. The rank of the observed value in the randomly generated distribution produces a regular permutational probability (Legendre and Legendre, 1998).

2.2.2. Site typology

The study sites presented were empirically pooled into six groups according to their pollution status and the type of

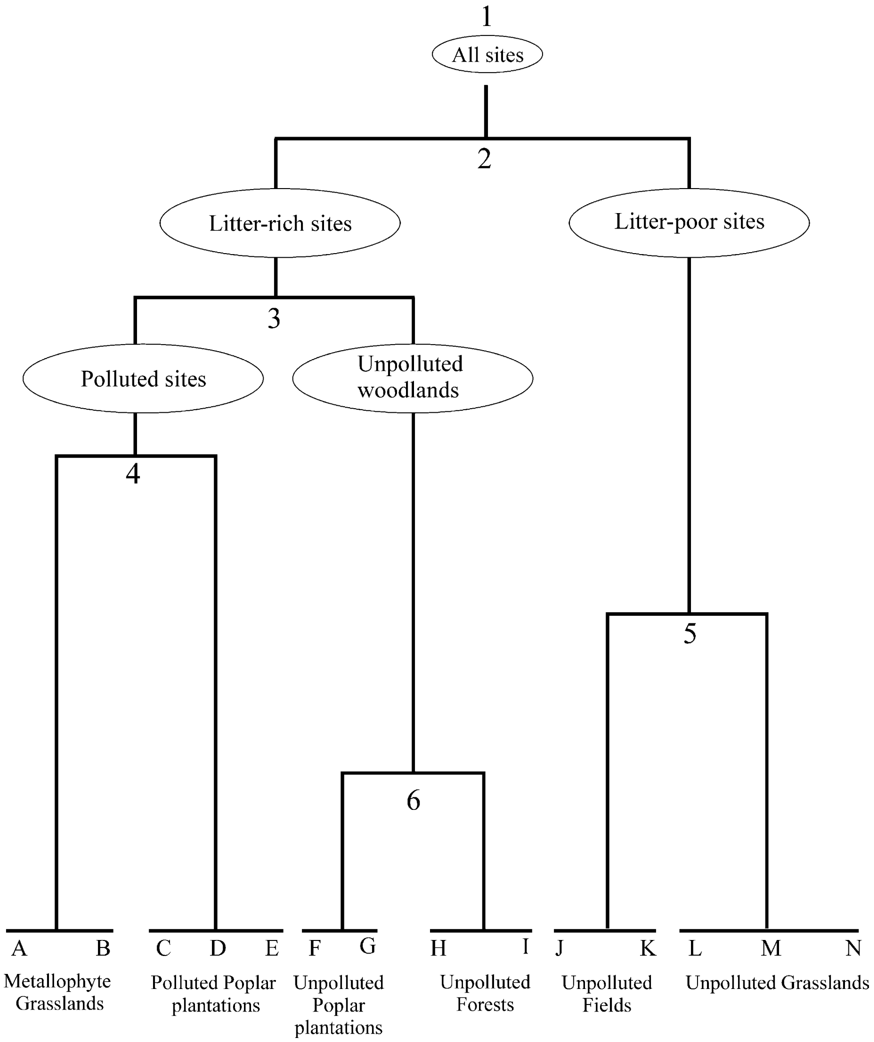

Fig. 1. Site a priori classification. Sites A to N were distributed into six groups according to their pollution status and the type of vegetation cover. Numbers represent the cluster level.

vegetation cover (Table 1, Fig. 1). The first level of the classification grouped all sites. The second level separated sites according to the importance of the litter layer and distinguished herbaceous unpolluted sites (litter-poor sites) from unpolluted woody and polluted sites (litter-rich sites). Level 3 distinguished polluted sites from unpolluted woodlands among litter-rich sites. Level 4 separated metallophyte grasslands from the polluted poplar plantations. Depending on the management practice, herbaceous unpolluted sites were divided at level 5 into grasslands and fields. The last level separated unpolluted natural forest from unpolluted poplar plantation (Nahmani and Rossi, 2003).

3. Results

3.1. Generalities

Of a total of 327 morphospecies observed in the different sites, 248 were encountered less than five times and were removed from indicator values analysis. Among the 66 species examined, only 19 were significant indicator species at one or more levels of the hierarchy (Table 3, Fig. 2): five coleoptera, two diplopoda, three chilopoda, three gastropoda, three annelida clittelata, one diptera, one trichoptera and one isopoda oniscoidae. Thus only 5.8% of the species have a significant indicator value.

At the family level (59 families or sub-families), 17 among the 47 families tested were significant indicators at least at one level of the hierarchy (Table 3, Fig. 3). These indicator families belong to the groups formerly identified (coleoptera, diplopoda, chilopoda, gastropoda, annelida clittelata, diptera, trichoptera, isopoda) and three additional groups, araneida, dermaptera and hymenoptera (formicidae). The proportion of the families that were indicator taxa reached 28.8%.

For ecological groups (28 groups, 21 analysed), 14 (50%) were indicators at one or more levels of the hierarchy (Table 3, Fig. 4).

Table 3
Indicator families and ecological groups in 14 polluted and unpolluted sites in northern France

Group of sites	Level	Species	Family	Ecological group
All sites	1		Lumbricidae (78.6)*	
Litter-rich sites	2	*Lithobius crassipes* (25)*	Lithobiidae (36.1)*	Chilopoda (63.5)*
		Philoscia muscorum (35.5)	Philosciidae (36.2)	Isopoda (36.2)
		Haplophilus subterraneus (31.5)	Geophilidae (40.4)	Diplopoda (26.4)
			Valloniidae (36.9)	Gastropoda (46.9)*
			Arionidae (27.7)	Arachnida (42.7)
			Enchytraeidae (42.2)	Epigeic earthworms (40.1)
Litter-poor sites	2	*Aporrectodea caliginosa* (60.9)		Endogeic earthworms (67.6)*
Polluted sites	3		Lithobiidae (26.8)	Gastropoda (25.9)
			Polydesmidae (25.5)	
Unpolluted woodlands	3	*Lumbricus castaneus* (30.9)	Enchytraeidae (87.3)*	Epigeic earthworms (44.1)*
		Haplophilus subterraneus (34.9)*	Geophilidae (45.3)*	Zoophagous Coleoptera (35.1)*
		Enoicyla pusilla (28.1)*	Limnephilidae larvae (28.1)*	Trichoptera larvae (28.1)*
		Philoscia muscorum (49.3)	Philosciidae (51.9)	Isopoda (51.9)
		Cryptops savignyi (28.1)	Scolopendridae (28.1)	Chilopoda (53.5)
		Diptera larvae sp 1 (28.1)*	Arionidae (27.1)	
Polluted poplar plantations	4	*Vallonia costata* (29.2)	Valloniidae (44.3)*	Diplopoda (35.9)*
		Polydesmus complanatus (28.1)	Polydesmidae (45.2)*	Gastropoda (45.9)
		Polydesmus denticulatus (25)	Lithobiidae (32.7)	
Metallophyte grasslands	4		Cucurlionidae (33.1)*	Phytophagous Coleoptera (26.7)*
			Formicidae (28)*	
Unpolluted grasslands	5	*Aporrectodea caliginosa* (61.9)*	Rutelidae (37.2)*	Rhyzophagous Coleoptera larvae (37.1)*
		Rutelidae hoplinae larvae sp 1 (32.2)*	Lumbricidae (55.2)	Endogeic earthworms (65.2)
		Elateridae larvae sp 2 (30)*		
Unpolluted fields	5			
Unpolluted poplar plantations	6	*Philoscia muscorum* (49.3)*	Philosciidae (54.1)*	Isopoda (54.1)*
		Clausilia bidentata (43.8)*	Arionidae (40.8)*	Epigeic earthworms (37.9)
		Lumbricus castaneus (42.8)*		
		Arion circumcriptus (40.8)*		
Unpolluted forests	6	*Cryptops savignyi* (56.3)*	Staphylinidae larvae (31.3)*	Zoophagous Coleotera larvae (45.4)*
		Diptera larvae sp 1 (56.3)*	Staphylinidae (31.7)*	Zoophagous Coleoptera (29.8)
		Dendrobaena attemsi (37.5)*	Scolopendridae (56.3)*	Chilopoda (34.1)
		Staphilinidae larvae sp 1 (30.7)*	Agelenidae (34.4)*	
		Habrocerus capillaricornis (25)*	Forficulidae (25)*	Forficulidae (25)*
		Elateridae larvae sp 1 (30.7)	Enchytraeidae (48.9)	
			Limnephilidae larvae (20)	

* indicates maximum indicator values.

3.2. Indicator value for the different taxonomical levels (Figs. 2–4)

3.2.1. Insecta

3.2.1.1. Hymenoptera—formicidae. In this group we tested two species but their indicator value was not significant. At the level of the sub-family, the Formicidae Myrmicinae was an indicator (IndVal = 28) of the metallophyte grassland (Fig. 3). Gathering the Myrmicinae and the Formicinae sub-families to form an ecological group led to a non-significant indicator value.

3.2.1.2. Coleoptera. Curculionidae: Since the 14 species of Curculionidae found in our samples were rare, none were tested. At the family level, the Curculionidae was a significant indicator of the metallophyte grasslands (IndVal = 33.1, Fig. 3). The ecological group of the phytophagous adult coleoptera (Table 3) was also an indicator of the metallophyte grassland although its indicator value was lower (IndVal = 26.7, Table 3, Fig. 4).

Staphilinidae: Among the 27 species collected at the 14 sites, only one could be tested, namely *Habrocerus capillaricornis*. It was a significant specialist of unpolluted forest sites (Table 1, Fig. 2). The family of Staphilinidae (considering the adult stage) was also an indicator of unpolluted forest with a higher indicator value (31.7) as compared to the species *H. capillaricornis* alone (25) (Figs. 2 and 3). Interestingly, the ecological group of zoophagous Coleoptera has a significant value for two nodes of the sites dendrogram with the indicator values of 35.1 and

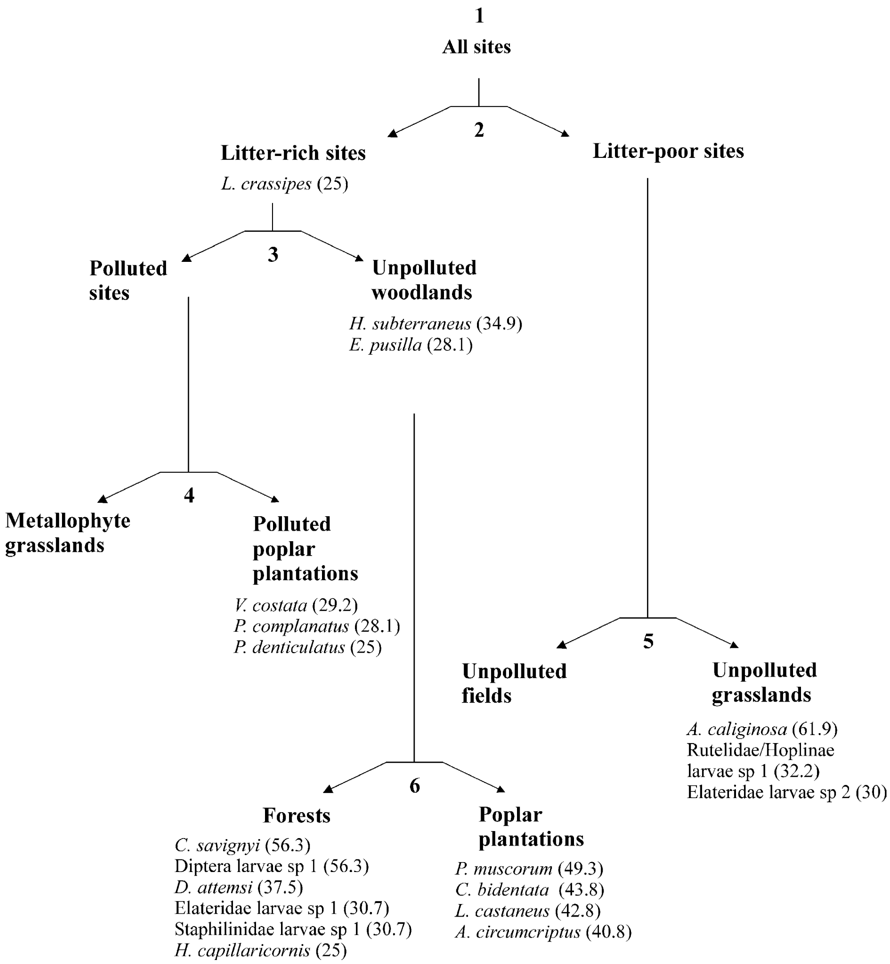

Fig. 2. Indicator species associated with different nodes of the site dendrogram. The indicator value is given between parentheses. Only maximum significant indicator values are presented.

29.8 for unpolluted woodlands and unpolluted forest, respectively (Table 3).

Staphilinidae (larvae): Nine species were identified at the larva stage, among which two were in sufficient numbers to be analysed. As for adult Staphilinidae, one species indicated unpolluted forests (sp1, IndVal = 30.7, Fig. 2). As a family, the Staphilinidae (larvae) was an indicator of unpolluted forests (IndVal = 31.3, Fig. 3). The ecological group of the zoophagous larvae was also an indicator of unpolluted forests (IndVal = 45.4, Fig. 4).

Elateridae (larvae): Two of the eight species were analysed and were found to be associated with unpolluted forests (species 1, IndVal = 30.7) and unpolluted grasslands (species 2, IndVal = 30; Fig. 2, Table 3). Other levels, family or functional groups did not show significant indicators.

3.2.1.3. Diptera larvae. Sixteen species (out of a total of 46) were tested and only one showed a significant indicator value. It was associated with unpolluted forest (species 1, IndVal = 56.3, Table 3, Fig. 2). Diptera proved difficult to distribute amongst families and ecological groups and those levels were not investigated.

3.2.1.4. Dermaptera. Although two species were recorded, none were analysed because they were very rare. At the level of family and ecological group, the Forficulidae was associated with unpolluted forest (IndVal = 25, Table 3, Figs. 2 and 3). Note that in that case the family and ecological group were identical.

3.2.1.5. Trichoptera (larvae). Enoicyla pusilla was found to be an indicator of unpolluted woodlands (IndVal = 28.1, Table 3, Fig. 2). The Limnephilidae family was associated with the unpolluted woodlands (IndVal = 28.1, Table 3, Fig. 3). The ecological group of the Trichoptera larvae was an indicator of the unpolluted woodlands (IndVal = 28.1, Table 3, Fig. 4).

3.2.2. Myriapoda

3.2.2.1. Diplopoda. Two species (*Polydesmus denticulatus* and *P. complanatus*) were indicators of the polluted poplar plantations (IndVal = 25 and 28.1, respectively, Table 3, Fig. 2). At the family level, the Polydesmidae was an indicator of polluted poplar plantation (IndVal = 45.2,

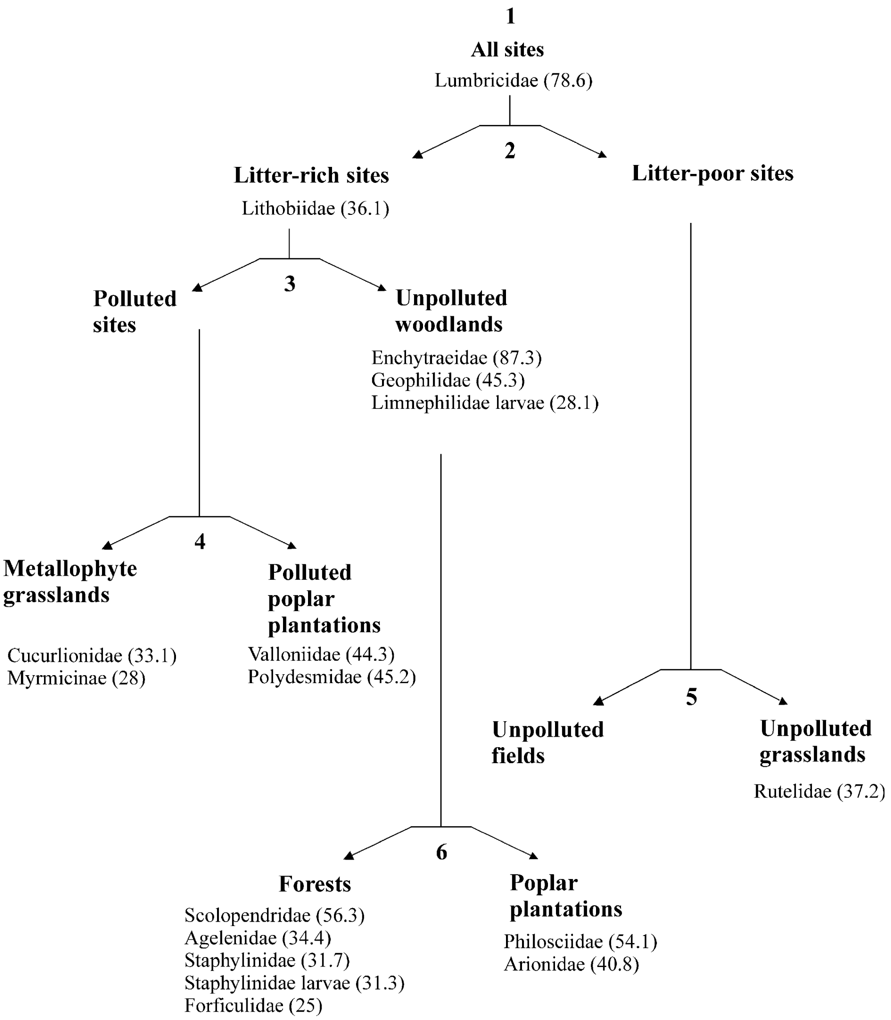

Fig. 3. Indicator families associated with different nodes of the site dendrogram. The indicator value is given between parentheses. Only maximum significant indicator values are presented.

Table 2, Fig. 3). The three other families were removed from indicator analysis due to scarcity. The diplopoda formed an ecological group associated with the polluted poplar plantations with an intermediate indicator value in comparison with both the species and the family levels (IndVal = 35.9, Table 3, Fig. 4).

3.2.2.2. Chilopoda. Six species out of 13 could be tested. *Lithobius crassipes* (Lithobiidae) was a generalist species indicating litter-rich sites (IndVal = 25, Table 3, Fig. 2). *Chryptos savignyi* (Scolopendridae) was associated with unpolluted woodlands and forests, respectively (IndVal = 28.1 and 56.3, Table 3, Fig. 2). *Haplophilus subterranus* (Geophilidae) had a significant IndVal value for litter-rich sites and unpolluted woodlands, respectively (IndVal = 31.5 and 34.9, Table 3, Fig. 2). Similarly, the Lithobiidae, and Geophilidae families were found to be generalist groups of the litter-rich sites and the unpolluted woodlands, respectively. The Lithobiidae family had significant indicator values for different nodes of the dendrogram. The Scolopendridae family was associated to the unpolluted forest sites. At the level of ecological group, chilopoda constituted a generalist group with a maximum and significant indicator value for litter-rich sites (IndVal = 63.5), and significant values for unpolluted woodlands and forests (53.5 and 34.1, respectively) (Table 3, Fig. 4).

3.2.3. Arachnida

Of the 55 morphospecies identified only five were analysed and none were indicator species. Among the 13 families identified, 11 could be tested and 1 (Agelenidae) appeared to be significantly associated with unpolluted forests (IndVal = 34.4, Table 3, Fig. 3). Taken as a whole, the ecological group of the Araneida appeared to be generalist of litter-rich sites (IndVal = 42.7, Table 3, Fig. 4).

3.2.4. Gastropoda

Five out of 20 morphospecies could be tested. Two snails and a slug had significant indicator values and were specialist species. The snail *Clausilia bidentata*

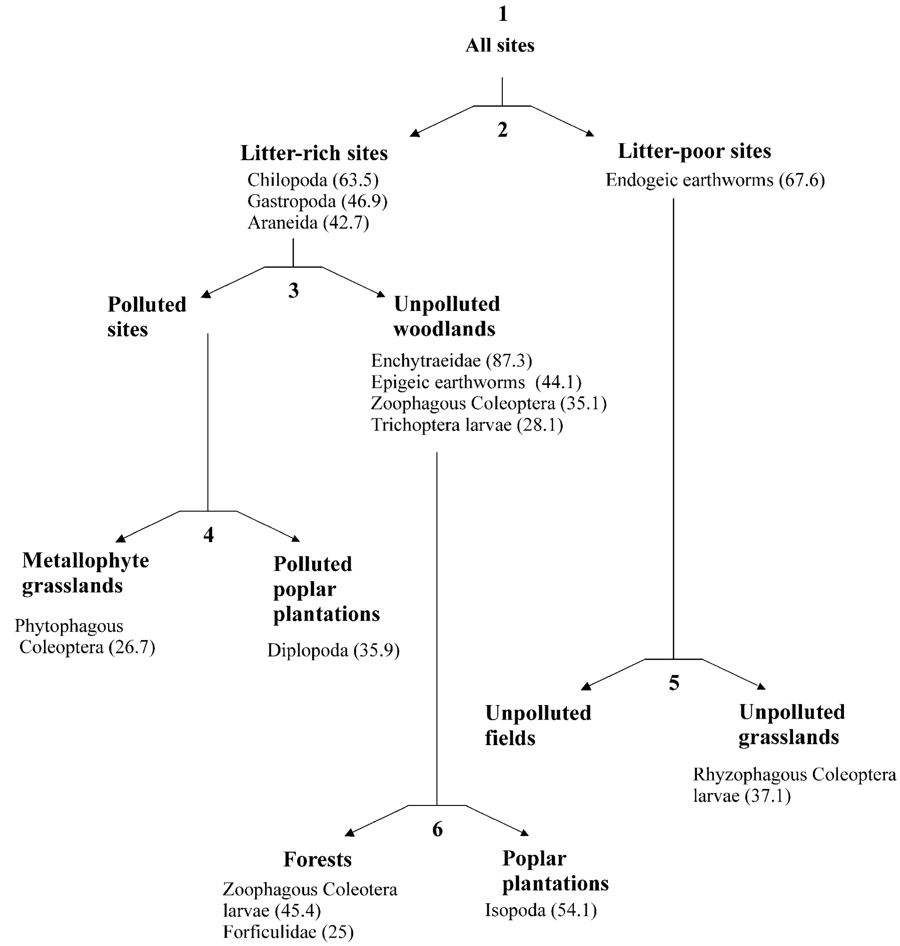

Fig. 4. Indicator ecological groups associated with different nodes of the site dendrogram. The indicator value is given between parentheses. Only maximum significant indicator values are presented.

(Clausiliidae) and the slug *Arion circumcriptus* (Arionidae) (IndVal = 43.8 and 40.8, respectively) were associated with the unpolluted poplar plantations. The snail *Vallonia costata* (Valloniidae) was an indicator of the polluted poplar plantations (IndVal = 29.2, Table 3, Fig. 2). The Valloniidae family was an indicator of the polluted poplar plantations while the Arionidae family was associated with unpolluted poplar plantations (Table 3, Fig. 2). The Gastropoda group was a generalist taxa associated with litter-rich sites (IndVal = 46.9, Table 3, Fig. 4).

3.2.5. Isopoda

Three species of Isopoda were examined and the most abundant, *Philoscia muscorum* (Philosciidae) was found to be a specialist species of the unpolluted poplar plantations (IndVal = 49.3, Table 3, Fig. 2). The same results were obtained for the Philosciidae family and the corresponding ecological group (Isopoda) (IndVal = 54.1, Table 3, Figs. 3 and 4).

3.2.6. Annelida—clittelata

Among the eight morphospecies recorded, three were indicator species. *Aporrectodea caliginosa* was a specialist of unpolluted grasslands (Fig. 2, Table 3). *Dendrobaena attemsis* was associated with unpolluted forests (Fig. 2, Table 3). *Lumbricus castaneus* was associated with unpolluted poplar plantations. Since the species composing the Enchytraeidae family were not identified, the group was only analysed at the family level. It indicated unpolluted woodlands (IndVal = 87.3, Fig. 3, Table 3). The Lumbricidae family had a significant indicator value only at the first level of hierarchical classification (all sites) (IndVal = 78.6, Fig. 3, Table 3). The latter family was split into three ecological groups (Lavelle, 1988), epigeic, endogeic and anecic earthworms. Epigeic earthworms were indicators of unpolluted woodlands (IndVal = 44.1, Fig. 4, Table 3), whereas the endogeic species formed a generalist group of litter-poor sites (IndVal = 67.6, Fig. 4, Table 3).

3.3. Changes in the proportion of indicators according to taxonomical level

Table 4 summarizes the number and the corresponding proportions (%) of generalist and specialist groups according to the taxonomical level considered. It can easily be seen that the proportion of specialist (generalist) groups

Table 4
Changes in the number and proportion of specialist and generalist groups according to the taxonomic level considered

Group of sites	Species	Families	Ecological groups	Species (%)	Family (%)	Ecological groups (%)
All sites	0	0	0	0	0	0
Litter-rich sites	1	1	3	5.26	5.88	21.43
Litter-poor sites	0	1	1	0	5.88	7.14
Polluted sites	0	0	0	0	0	0
Unpolluted woodlands	2	3	4	10.53	17.65	28.57
Total generalist groups	3	5	8	15.79	29.41	57.14
Polluted poplar plantations	3	2	1	15.79	11.76	7.14
Metallophyte grasslands	0	2	1	0	11.76	7.14
Unpolluted grasslands	3	1	1	15.79	5.88	7.14
Unpolluted fields	0	0	0	0	0	0
Unpolluted poplar plantations	4	2	1	21.05	11.76	7.14
Unpolluted forests	6	5	2	31.58	29.41	14.29
Total specialist groups	16	12	6	84.21	70.59	42.86
Total all groups	19	17	14	100	100	100

decreases (increases) while species are aggregated to form families and families to form ecological groups.

4. Discussion

4.1. Generalist groups associated to litter-rich sites

Only three species out of a total of 338 were generalists (Table 4) amongst which one species, the centipede species *L. crassipes* (Lithobiidae), was characteristic of litter-rich sites (Fig. 2). This result indicates that the species is not particularly affected by high pollutant level since litter-rich sites include the polluted sites investigated in this study. Previous studies showed that some species within that zoological group are able to survive to metal contaminated soils (Descamps et al., 1996; Grelle et al., 2000).

Using the family/sub-family scale led to a larger number of generalist groups. One generalist family was associated with the litter-rich sites (Fig. 2), namely the Lithobiidae. It is likely that the pattern of the generalist species *L. crassipes* (see above) is responsible for this result.

The Araneida ecological group appeared as an indicator of litter-rich sites. This group comprises abundant and diverse predators in both natural and disturbed terrestrial ecosystems (Ysnel and Canard, 2000). It seems to respond mainly to changes in habitat structure, landscape structure and composition (Marc et al., 1999; Ysnel and Canard, 2000; Perner and Malt, 2003). Regulation of Cu and Zn seems to occur but generally, arachnida were found to show a high accumulation of cadmium and lead (Rabitsch, 1995c). The ecological group of the Chilopoda was a generalist indicator associated with all litter-rich type of habitat. As such, it behaves like the Lithobiidae family (see above) but also follow the distribution of the Geophilidae. The gastropoda appeared also as generalists associated with litter-rich sites. As for the Chilopoda, this is explained by the presence of various families and species associated with different litter-rich types of habitat (e.g. Valloniidae and Arionidae associated with the polluted and unpolluted poplar plantations, respectively).

4.2. Specialist species/groups

Most of the indicator taxa reported here are specialists, that is, they are closely associated to a single habitat type (Dufrêne and Legendre, 1997). This may be partly due to the fact that our survey mainly comprised sites with dramatically contrasting ecological attributes (e.g. open habitats/forests; highly polluted/unpolluted). At the species scale, all habitats except unpolluted fields and metallophyte grasslands had associated specialists (Fig. 2).

Interestingly there were three indicator species linked to the polluted poplar plantations. These were two species of the genus *Polydesmus* (Diplopoda) and one species of the genus *Vallonia* (Gastropoda) (Table 3). Successful regulation of essential nutrients employing a storage/detoxification strategy is known to exist in Diplopoda (and within the genus *Polydesmus*) but the sensitivity to metal greatly depends on the species considered: certain species are good indicators of polluted sites, e.g. *Polydesmus angustus* whereas other species are sensitive, e.g. *P. gallicus* (Read et al., 1998). Furthermore, terrestrial Gastropoda are known to accumulate high amounts of cadmium and copper (Ireland, 1979; Dallinger and Wieser, 1984) and to be extremely tolerant of high concentrations of cadmium in their close environment and in their tissues. Copper accumulation is mainly linked to the respiratory system of the Gastropoda, which is based on a copper-rich respiration protein (hemocyanin; Chabicovsky et al., 2003). Thus it appears that some Gastropoda species are adapted to simultaneously handling and accumulating large amounts of the essential copper and non-essential elements.

Both the Valloniidae and the Polydesmidae families are indicators of polluted poplar plantations, probably because the pattern of *V. costata*, *P. complanatus* and *P. denticulatus*. Two additional indicator groups appear at the family level and they are associated with the metallophyte grasslands (the most polluted sites studied here): the Curculionidae and the Formicidae.

Studies of the value of Curculionidae as bioindicators and the effects of metals on these organisms are rare (Rabitsch, 1995a; Lapointe et al., 2004). At a lead smelting site in Austria, Rabitsch (1995a) reported that metal concentrations within Coleoptera decreased in the following order: Staphilinidae > Carabidae > Curculionidae. It was concluded that differences in feeding preferences and regulatory mechanisms specific to higher taxonomic levels were responsible for that pattern. Therefore, the Curculionidae appeared to be a robust indicator of the highly contaminated metallophyte grasslands. The group is probably favoured by the high density of the herbaceous cover. Ants are known to constitute good bioindicators of forest and agriculture managements (Lobry de Bruyn, 1999) and off-mining impacts (Rabitsch, 1995c; Majer and Nichols, 1998). Ants are able to accumulate high levels of metals (macroconcentrator), and to develop metal regulatory capabilities and strategies (Dallinger, 1993; Rabitsch, 1995b). The evidence of decreased lead cadmium and zinc level with increasing distance from an emission source of metal may prompt the consideration of ants as being of bioindicative value (Rabitsch, 1995b). In Formica ants, metals and particularly Cd may diminish the population density (Mukherjee and Nuorteva, 1994). However, exceptions to this generality exist, with for example, similar ant communities in a mine and a reference site because of the similarity of the ground-layer conditions. Puszkar (1980) noted an increase in ant productivity in an intermediately polluted environment, based on the negative impact of pollution on other competitive soil surface predators. In our study, the Formicidae group was associated to the metallophyte grasslands, seemingly favoured by the ground layer conditions, a particularly important factor for ants (Andersen et al., 2003).

Using ecological groups led to two indicators, highly linked to the former families. The phytophagous Coleoptera were indicators of the metallophyte grasslands mainly because of the high density of the Curculionidae in these habitats. The Diplopoda group was an indicator of the polluted poplar plantations, essentially because it expressed the high densities of *P. complanatus* and *P. denticulatus*.

4.3. The effect of taxonomical/ecological resolution

In this paper, we changed the taxonomical/ecological resolution by grouping species into families and species/families into ecological groups on the basis of the known feeding regime and ecological requirements. The main obvious consequence of such grouping is the decrease in the number/proportion of specialist groups. The proportion of specialist indicator groups ranges from 84% at the species level to 71 and 43% at the family and ecological group level. This can be explained by the fact that families and ecological groups associate various species that are distributed in different types of habitat. As a result, ecological groups and to a lesser extent families, are more likely to be generalists. As an example, the Lumbricidae family is a generalist group associated with open habitat (litter-poor sites), whereas the sole species having a significant indicator value in this type of sites is *A. caliginosa*—a specialist species associated to the unpolluted grasslands. Other Lumbricidae include specialist species of unpolluted forests (*D. attemsi*) and unpolluted poplar plantations (*L. castaneus*). In this example, putting together various species to form a high taxonomical level group (the family) leads to a loss of information. The resulting grouping albeit phylogenetically correct is ecologically meaningless.

On the other hand, this is not always true at the scale of the family when it comprises one abundant specialist and other species with lower density. For example, *V. costata* is indicator of the polluted poplar plantation as is its family (Valloniidae). This is true also of, e.g. *C. savignyi* or *P. muscorum*. Furthermore, species closely related and sharing some resistances/adaptations to pollution or other human-induced perturbations may be beneficially gathered into families in particular when the density of populations display high spatial variability. This is typically the case for social insects like ants in this study or, e.g. termites in tropical soils. The spatial aggregation of such species is high thus leading to high variance of abundance data. This may cause low values of the fidelity term (Eq. (2)) and consequently low and non-significantly indicator value term. Pooling different species with somewhat similar patterns (ecological tolerance/preferenda) could smooth abundance data and prevent a sharp decrease in the fidelity term. This is the case of the Formicidae family in this study. At the species scale, there is no significant indicator taxa whereas the Myrmicinae sub-family is a significant indicator (specialist) of the metallophyte grasslands. Therefore, grouping species may allow numerical difficulties to be overcome. However, species gathering should ideally only involve species showing similar ecology (with regards to the problem at hand) otherwise specialist species may be lost in favour of generalist groups. This is what we report here in different instances (see the case of the Lumbricidae above). Broad groups are likely to yield either non-significant indicator values or to provide high level generalist groups that are non-informative and obvious (e.g. epigeic earthworm associated with unpolluted litter-rich sites).

Creating ecological groups from species and families raises similar, if not greater difficulties. We show here that the increase of the proportion of generalists units is even more marked than in the case of the family level (Table 4). The groups that emerge from the analysis are often obvious (e.g. epigeic earthworms are associated to unpolluted woodlands while endogeic species are generalist of open habitats) and mainly generalists.

The scale of the taxonomical resolution to be used depends on the goals of the study. For conservation purposes, the use of the species level is obvious. However, other larger scales may be useful when one searches for indicators of sustainable land use (Büchs, 2003), where species level is not strictly required and where functional or ecological group may be the target of conservation actions. The problem with the family level is that it does not always form homogeneous groups with regards to a given human-induced perturbation. In a study of metal pollution impact upon woodland invertebrates, Read et al. (1998) illustrated the species dependency of the sensitivity to metal within a given genus. In the family of the Polydesmidae, the species *P. angustus* proved a good indicator of metal pollution, whereas *P. gallicus* was very sensitive. Clearly, gathering these species into a single group leads to loss of the interesting information. This problem may be overcome by grouping only species with similar behaviour towards pollution or any kind of perturbation. But obviously this implies that indicator species are already known, hence a circular reasoning.

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