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Functional structure and composition of Collembola and soil macrofauna communities depend on abiotic parameters in derelict soils

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ABSTRACT

In the last decades, anthropogenic disturbances have altered the ability of soils to provide diverse functions. Certain anthropogenic soils, with a low fertility level and often contaminated, ended up underused and derelict. Although derelict for humans, these soils may be refuges for biodiversity, but their biological functioning remains poorly understood. To this end, a trait-based approach of soil invertebrate communities might be an effective predictor of ecosystem state. The present work aims to highlight the *in situ* links between the abiotic characteristics of derelict soils and the taxonomic and functional structure and composition (through a trait-based approach) of macrofauna and Collembola communities inhabiting these soils. We studied 6 different derelict soils: two soils from coking plants, one soil from a settling pond, two constructed soils, and an inert waste storage soil. We measured fifteen abiotic soil parameters that inform on fertility and contamination. We took into account sixteen traits and ecological preferences to characterize the functional structure and composition of Collembola and macrofauna communities. Soil fertility (organic matter content, C:N ratio, P, Ca and Mg concentrations, cation-exchange capacity, and clay content) and moderate contamination (Pb, Cd, Zn, and PAH concentrations) altered the taxonomic and functional composition of Collembola and macrofauna communities by selecting traits such as body length, pigmentation, vertical distribution, diet type, and habitat preference. Compost-amended constructed soil properties selected taxonomic and functional community composition of slightly disturbed soil. In contrast, metal-contaminated constructed soil harbored a higher proportion of Collembola displaying the traits and ecological preferences of instable ecosystems. The study of functional profiles of Collembola and macrofauna communities in the derelict soils evidenced that they support different communities with more or less wide functional potential. It underlines the interest of multiple biotic component studies to reach a better ecosystem description.

1. Introduction

Soils are complex ecosystems, described as multifunctional systems because many components interact inside them (Kibblewhite et al., 2008; Briones, 2014). Nevertheless, over the last decades growing evidence has emerged about the negative impact of anthropogenic disturbances on the ability of soils to provide functions (Levin et al., 2017) and occasionally to host biodiversity (Orgiazzi et al., 2016). In this context, the closing down of steel, shipbuilding or metal manufacturing industries because of economic issues and the closing down of mining sites in different European countries have resulted in land abandonment and altered ecosystem functioning (Wong and Bradshaw, 2002). Sometimes called greenfields, wastelands, uncultivated/vacant/abandoned lands, the soils of these derelict lands can be disturbed, *i.e.* characterized by a low fertility level (Dickinson, 2003) and/or sometimes by contamination (Morel et al., 2005). These specific abiotic parameters can alter soil functions likely to be important for agriculture and lead to surfaces being unmanaged and underused (Cundy et al., 2016). In Vincent et al. (2018), we showed that derelict soils could have low organic matter and nitrogen contents, a low cation exchange capacity, alkaline conditions with cations occasionally lacking or in excess, and moderate organic and inorganic contamination linked to their history. Biotic parameters (*i.e.* plant, fauna and microorganism density and richness) co-varied more with soil fertility proxies than with soil contamination parameters in moderately contaminated derelict soils. Once soils are underused and abandoned by humans, they may turn into refuges for biodiversity provided that abiotic parameters are not extreme for life (Baranova et al., 2014). Derelict soils have been

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Table 1

Abiotic parameters of the six derelict soils. Means ± SD (n = 5, except for soil F where n = 4). Soil classification according WRB (2014); localization in the Lambert 93 projection in m; age is the time lapse from the last anthropogenic action (years); clay and WHC in %; CEC in $cmol^{+}.kg^{-1}$ dry soil; soil pH in water; Olsen Phosphorous in $mg.kg^{-1}$ dry soil; OM in ‰; Exchangeable Ca, K, Mg, Na in $mg.kg^{-1}$ dry soil, Available and total Cd, Pb, Zn in $mg.kg^{-1}$ dry soil; and PAH (Polycyclic Aromatic Hydrocarbons) concentrations in $mg.kg^{-1}$ dry soil. For more details, see Vincent et al. (2018).

Soil abbreviation	CS	WL	CP1	SP	CP2	CCS
Soil name correspondence with Vincent et al., 2018	A	B	C	D	E	F
Site type and name	Experimental constructed soil (Biotechnosol)	Non-hazardous waste landfill (Retonfey)	Coking plant site (Homécourt)	Settling pond site (Moyeuvre-Petite)	Coking plant site (Micheville)	Experimental constructed and contaminated soil (Jeandelaincourt)
Soil classification	Spolic Garbic Technosol	Skeletic Technosol	Spolic Technosol	Spolic Technosol	Spolic Technosol	Spolic Technosol
Composition	paper mill waste, thermal desorption-treated PAH-contaminated soil, and green-waste compost	ground construction and demolition wastes	former coking plant site	settling pond site filled with steel sludge	former coking plant site	biopile-treated PAH-contaminated soil mixed with metal-contaminated sludge
Year of construction	2007	2011				2013
Year of abandonment			1980	1981	1975	
Age	8	4	35	34	40	2
Localization	E:918202 N:6905686	E:942352 N:6897630	E:918487 N:6905891	E:920222 N:6911528	E:942262 N:6897475	E:938477 N:6864617
Texture	Silt loam	Silty clay loam	Loamy sand	Sandy loamy	Loam	Silt loam
Clay	11	40	6	4	27	15
WHC	95 ± 7	59 ± 8	63 ± 5	58 ± 4	70 ± 1	64 ± 1
CEC	22.0 ± 2.9	17.2 ± 3.3	17.2 ± 1.8	11.3 ± 0.7	15.5 ± 1.4	10.1 ± 0.4
pH	7.9 ± 0.2	7.9 ± 0.1	7.9 ± 0.1	8.4 ± 0.2	7.2 ± 0.2	8.3 ± 0.4
Olsen Phosphorous	62 ± 5	25 ± 17	39 ± 16	44 ± 10	36 ± 2	44 ± 10
C:N	30 ± 6	28 ± 6	26 ± 5	65 ± 20	20 ± 3	37 ± 16
OM	39.7 ± 5.9	3.2 ± 1.4	16.7 ± 6.3	13.3 ± 2.8	4.8 ± 3.0	2.8 ± 0.8
$Ca_{exchangeable}$	292 ± 44	713 ± 144	903 ± 405	2031 ± 240	786 ± 84	1123 ± 130
$K_{exchangeable}$	706 ± 105	491 ± 24	155 ± 36	377 ± 30	131 ± 50	218 ± 36
$Mg_{exchangeable}$	84 ± 14	152 ± 38	103 ± 6	312 ± 47	47 ± 15	72 ± 34
$Na_{exchangeable}$	37 ± 19	34 ± 28	11 ± 3	42 ± 11	14 ± 14	55 ± 29
$Cd_{available}$	0.22 ± 0.05	0.03 ± 0.01	0.16 ± 0.05	0.15 ± 0.01	0.10 ± 0.03	9.07 ± 1.5
$Pb_{available}$	13 ± 3	14 ± 10	46 ± 14	18 ± 5	14 ± 6	110 ± 60
$Zn_{available}$	29 ± 9	8 ± 6	45 ± 20	25 ± 6	7 ± 2	308 ± 189
Cd_{total}	1.1 ± 0.5	0.1 ± 0.2	0.1 ± 0.7	1.4 ± 0.1	0.1 ± 0.1	23.6 ± 6.9
Pb_{total}	150 ± 53	41 ± 26	346 ± 106	339 ± 50	37 ± 10	460 ± 73
Zn_{total}	345 ± 37	131 ± 2	1162 ± 396	1196 ± 122	116 ± 23	1813 ± 302
Σ16 PAH (US-EPA)	170 ± 49	12 ± 12	179 ± 136	97 ± 54	142 ± 90	10 ± 4

reported to harbor a rich invertebrate biodiversity: insects (Bonthoux et al., 2014), beetles (Eyre et al., 2003), carabids (Small et al., 2006), earthworms and Collembola (Butt and Briones, 2017). However, the biological functioning of derelict soils remains poorly understood as compared to forest or agricultural lands.

In this vein, trait-based approaches focusing on the characteristics of individuals provide an interesting tool to assess soil functioning (Verberk et al., 2013). Pey et al. (2014) defined traits in soil invertebrate studies as "morphological, physiological, phenological or behavioral features measurable at the individual level, from the cell to the whole-organism level, without reference to the environment or any other level of organization". Traits could be considered as functional because they impact organism fitness directly and indirectly (Violle et al., 2007). Finally, functional traits can help to understand the effect of environmental stressors on soil communities (Auclerc et al., 2009; Vandewalle et al., 2010; Hedde et al., 2012; Salmon and Ponge, 2012). In recent years, traits have been recognized as effective predictors of exposure to disturbances (metal contamination in Hedde et al., 2012; restoration practices in Rosenfield and Müller, 2017), or of management strategies such as intensive agriculture, polyculture and monoculture (Wood et al., 2015; Sechi et al., 2017) to better understand the soil functional community structure and composition.

The functional community composition of the soil fauna is linked to soil abiotic parameters. For example, in urban soils, the proportion of Collembola with a sexual reproduction type was positively correlated with total Cu and Ni concentrations, and the proportion of pigmented Collembola was positively correlated with total Cr, Pb and Zn concentrations (Santorufo et al., 2015). The proportion of Collembola living belowground (with the following trait attributes: small size, reduced or absent sensorial organs and furca, non-sexual reproduction type) in coal mine spoil tip soils was found associated to a coarser soil texture and higher nitrogen and organic matter concentrations (Vanhee et al., 2017). In parallel, the proportion of macroinvertebrates with a soft body decreased when metal contamination increased (Hedde et al., 2012), and the body size of ants was found driven by soil granulometry (Costa-Milanez et al., 2017). Moreover, other authors showed that soil age played a key role in the functional community composition by selecting certain traits such as moisture or light requirement in carabid communities (Aubin et al., 2013) or the feeding group for macrofauna communities (Frouz et al., 2013). To our knowledge, existing studies dealing with trait-based approaches in anthropogenic sites focussed on only one group of soil invertebrates (Collembola or carabids or macrofauna) and were carried out on highly contaminated and/or low fertile soils. Furthermore, there are too few studies considering the links between soil chemistry parameters and trait-based invertebrate community composition (*e.g.* Salmon and Ponge, 2012; Santorufo et al., 2014; Santorufo et al., 2015; Martins da Silva et al., 2016).

The present work aims to characterize which environmental factors shape macrofauna and Collembola invertebrate communities and their functional structure and composition in derelict soils characterized by moderate contamination and/or low fertility. We hypothesized that the soil characteristics related to past industrial activities and/or to the materials used for construction drove the composition of invertebrate communities by selecting certain traits and ecological preferences. We studied 6 different derelict soils: two soils from coking plants, one soil from a settling pond, two constructed soils, and an inert waste storage