

Vegetation Shapes Aboveground Invertebrates Communities More Than Soil Properties and Pollution on a Metal Contaminated Site

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Abstract

Pollution with trace metals (TM) has been shown to affect diversity and/or composition of plant and animal communities. While ecotoxicological studies have estimated the impact of TM contamination on plant and animal communities separately, ecological studies have widely demonstrated that vegetation is an important factor shaping invertebrate communities. It is supposed that changes in invertebrate communities under TM contamination would be explained by both direct impact of TM on invertebrate organisms and indirect effects due to changes in plant communities. However, no study has clearly investigated which would more importantly shape invertebrate communities under TM contamination. Here, we hypothesized that invertebrate communities under TM contamination would be affected more importantly by plant communities which constitute their habitat and/or food than by direct impact of TM. Our analysis showed that diversity and community identity of flying invertebrates were explained only by plant diversity which was not affected by TM contamination. Diversity of ground-dwelling (GD) invertebrates in spring was explained more importantly by plant diversity (27% of variation) than by soil characteristics including TM concentrations (8%), whereas their community identity was evenly explained by plant diversity and soil characteristics (2-7%). In autumn, diversity of GD invertebrates was only explained by plant diversity (12%), and their identity was only explained by soil characteristics (8%). We conclude that vegetation shapes invertebrate communities more importantly than direct effects of TM on invertebrates. Vegetation should be taken into account when addressing the impacts of environmental contamination on animal communities.

1 Introduction

Trace metals (TM) are naturally occurring elements, whose concentrations in the environment can be dramatically increased by various anthropogenic activities, which can deeply impact wildlife (Eisler, 2000; Nordberg et al., 2014). Although technical and regulatory improvements have considerably reduced the emission of some TM, legacy TM contamination persists in nature because TM are non-degradable chemicals. The emission of other elements such as antimony failed to be drastically reduced (He et al., 2019) and emerging elements (e.g. rare earth elements) are increasingly emitted into the environment in relation to their use in new technologies (Gwenzi et al., 2018). Altogether, TM persist in nature and continue to affect ecosystems (EMEP, 2013). Harmful effects of TM contaminations are observed at several biological levels (Walker et al., 2012). At community level, diversity indices have commonly been used as indicators for estimating pollutants' effects on plants and invertebrates (Zvereva et al., 2008; Zvereva and Kozlov, 2012, 2010). Ecosystems undergoing strong disturbances display many negative responses, one of which being the decrease of biodiversity (Odum, 1985). In terrestrial ecosystems, it has been frequently reported that diversity of plants was negatively affected by soil TM contamination (Bes et al., 2010; Dazy et al., 2009; Ginocchio, 2000; Vidic et al., 2006). Change in plant community composition along a gradient of TM soil contamination has also been reported (Strandberg et al., 2006). However, responses of plant community diversity and composition to soil TM contamination vary according to TM and vegetation types (Zvereva et al., 2008). A similar framework has been highlighted in biodiversity and

composition of terrestrial invertebrate communities under TM contamination. Some studies have stressed negative correlations between diversity of invertebrates and soil TM contamination (Paoletti et al., 1988; Read et al., 1987; Spurgeon and Hopkin, 1996), whereas others have focused on changes in invertebrate community structure and composition rather than in diversity indices (Babin-Fenske and Anand, 2011; Migliorini et al., 2004; Nahmani and Lavelle, 2002). Both ground-dwelling and flying invertebrates might be impacted by metal environmental contamination because either or both larval and adult stages can be exposed through direct cutaneous contact with contaminated substrates and/or through contaminated food consumption (Hopkin, 1989).

While impacts of metal contamination on biodiversity have widely been studied separately in both plants and invertebrates, interactions between plants and animals are suggested as one of key factors in influencing the responses of communities to environmental TM contamination (Bol'shakov et al., 2001; Eeva et al., 2012; Storm et al., 1993). In fact, some results have nuanced the potential relationships between plant and invertebrates diversity in sites contaminated by TM suggesting a critical role of direct effects of environmental contamination (Brändle et al., 2001; Read et al., 1998), while other works have suggested possible effects of vegetation on composition of invertebrate communities under TM contamination (Grelle et al., 2000; Nahmani and Rossi, 2003). However, no study, to our knowledge, has specifically attempted to disentangle the relative importance of plant community *versus* soil TM contamination in shaping invertebrate communities. In contrast, ecological studies have clearly shown that vegetation is an important factor shaping above- and below-ground invertebrate composition and structure of assemblages in grassland (Brose, 2003; Haddad et al., 2001; Knops et al., 1999; Scherber et al., 2010; Siemann, 1998) and woodland (Fraser et al., 2007; Humphrey et al., 1999; Scherber et al., 2014; Sobek et al., 2009) ecosystems. Although potential underlying mechanisms are still debated (Borer et al., 2012; Haddad et al., 2009), diversified plant communities could provide a variety of resources for a greater number of herbivore species (Hutchinson, 1959), shelters from predators and/or more stable prey availability for predators, supporting their higher diversity and abundance (Root, 1973). Given the determinant influence of vegetation on invertebrate communities, we hypothesized that diversity and composition of invertebrate community under soil TM contamination would be more importantly explained by changes in vegetation as indirect effects of soil TM contamination than by direct effects of TM on invertebrate organisms.

In the present study, the potential effects of TM soil contamination and diversity of plants on diversity and composition of invertebrate communities were assessed in a smelter-impacted area in northern France, using diversity of taxa (i.e. alpha diversity) and its variation (i.e. beta diversity) at local level. We specifically aimed at disentangling and quantifying the relative importance of soil contamination and of plant community features on invertebrate community characteristics. We first explored (i) the relationship between plant diversity, soil TM concentration and soil properties related to TM bioavailability and toxicity in order to identify potential changes in vegetation determined by soil TM contamination. We then analyzed (ii) the effects of plant diversity on diversity and identity of invertebrate communities independently from TM contamination and soil properties and (iii) the effects of TM contamination and

soil properties on invertebrate communities independently from plant diversity in order to quantitatively compare their respective effects.

2 Materials And Methods

2.1 Study sites

This study was carried out in the surroundings of the former lead (Pb) and zinc (Zn) smelter named “Metaleurop Nord” located in Northern France (Noyelles Godault, Hauts-de-France, France). The smelter was in activity from 1894 to 2003 and was the only producer of primary Pb in France. Its pyro-metallurgic process had generated large quantities of dust containing many metals. For instance, about 1.0 ton of cadmium (Cd), 16.9 tons of Pb and 31.6 tons of Zn were released in 2002, despite the implementation of technical improvements during the 1970s (DRIRE, 2003). An area of approximately 120 km² around the smelter is still affected by dust emission released from Metaleurop Nord and from another large Zn smelter named “Umicore” close to Metaleurop Nord (Douay et al., 2008). Several studies have revealed high soil TM contamination in the surrounding soils. For instance, concentrations in agricultural top soils are as high as 21 mg kg⁻¹ of dry soil for Cd, 1132 mg kg⁻¹ for Pb, and 2167 mg kg⁻¹ for Zn (Sterckeman et al., 2002), whereas concentrations of these metals reached up to 67, 4890 and 2685 mg kg⁻¹, respectively, in the upper organic layers of grasslands around the smelter (Sterckeman et al., 2000). In the study of Fritsch et al. (2010), total concentrations of the three metals in soils sampled from wooded patches reached up to 236, 7331 and 7264 mg kg⁻¹ of dry soil, respectively.

The present study was undertaken on six sites of 25 ha (500m x 500m) in the surroundings of Metaleurop Nord. The area is a densely urbanized zone mixed with arable lands (ploughed fields mostly, grassland), forest and planted woods, and shrublands in derelict lands. Five sites among the six ones were located within an area of 40 km² (5 x 8 km) including the smelter in its center (50°25'42 N and 3°00'55 E). The other site was located about 10 km northeast of the former smelter and is considered as a control site due to its relatively low soil TM contamination: 0.9 - 2.4, 43 - 200, 89-278 mg kg⁻¹ of dry soil for Cd, Pb, and Zn, respectively (Fritsch et al., 2010), which are similar to the regional reference values (Sterckeman et al., 2007). The six sites were chosen for representing a gradient of TM soil concentrations (control, low, moderate, and high contamination, referred to as “TE2”, “103”, “117”, and “097”, respectively, Table 1).

2.2 Field inventory of plants and invertebrates

In each of the six sites, plants, flying and ground-dwelling invertebrates were surveyed as summarized in Figure S11 and described below, focusing on woody habitats (natural forests, tree plantations such as poplar groves, or copses and hedgerows in natural or cultivated lands and urban parks). Invertebrates were surveyed in woody patches where soils had been sampled and analyzed in previous studies (Fritsch et al., 2010).

Vegetation survey was realized on each of the six study sites from 4th June to 5th September 2012. Vascular plant taxa were identified separately in three different strata: tree stratum (woody species > 8 m high), shrub stratum (woody species < 8 m high), and herbaceous stratum. Plants were identified in the field at species level following Dudman and Richards (1997) and Lambinon et al. (2004). Cover-abundance was visually estimated as vertically projected area for each species following Braun-Blanquet et al. (1952). In total, 236 plant taxa were listed in the three strata: 25 species in tree stratum; 42 species in shrub stratum and 193 species in herbaceous stratum (N.B. some plant taxa were observed in several strata).

Inventory of invertebrates was carried out on each of the six study sites in spring (April) and in autumn (September and October) 2012 by two types of trapping: pitfall traps and yellow pan traps. It is important to note that this sampling aimed at providing a snapshot of invertebrate communities rather than a full description of invertebrate communities, which would have required a longer sampling period.

The pitfall trap is one of the most frequently used methods for sampling epigeic invertebrates such as ground beetles, rove beetles, wandering spiders, and ants (Leather, 2005). Three 800ml polypropylene beakers with neither roof nor preservative fluid were set at 15m intervals between each of them in woody patches where plants were present in all the three strata, constituting and hereinafter referred to as a “trap line”. From two to eight trap lines were set per season (i.e. spring and autumn) on each of the six study sites (i.e. 36 trap lines were used in spring and 32 in autumn, Table 1).

The yellow pan trap is frequently used for sampling flying insects. Trapping color plays a determinant role in the effectiveness with which different insect groups are caught, but yellow color is most efficient for catching a wide range of phytophagous insects and their predators or parasitoids (Kirk, 1984). One to three yellow pan traps with soap mixed water were set on the ground on each of the six study sites and for each season in woody patches where plants were present in all the three strata (i.e. 12 yellow pan traps were used in spring and 12 in autumn, Table 1).

Locations of the two types of traps were geo-referenced. Both pitfall and yellow pan traps were checked every morning for three consecutive days, and then removed from the field. Captured invertebrates were stored in ethanol or in freezer at -20°C and then identified in laboratory at the finest possible taxonomic level by morphological characteristics. The main references used for invertebrate determination were Coulon (2003), Forel and Leplat (2001), Jeannel, (1941) and Trautner and Geigenmueller (1987).

Fauna captured by pitfall and yellow pan traps were considered as “ground-dwelling (GD)” and “flying” invertebrates, respectively. Collembolans were removed from our inventory. Most of the individuals were identified at family level (GD 74% and flying 78%), but other were identified at order (GD 24% and flying 21%) or class levels (GD 2% and flying 1%) (cf. Supporting Information SI Spreadsheet file). Twenty-four taxa at different taxonomic levels (three classes, three orders and 18 families) were listed in the GD invertebrates, while 95 taxa (one class, four order and 90 families) were listed in flying invertebrates. Among the 90 flying invertebrate families, six families of Diptera larvae (Chironomidae, Culicidae,

Limoniidae, Psychodidae, Simuliidae, and Sciomyzidae) mainly occur in aquatic habitats, and seven families of Diptera larvae (Ceratopogonidae, Tipulidae, Dolichopodidae, Empididae, Phoridae, Syrphidae, and Scathophagidae) could occur in aquatic or semi-aquatic habitats, depending on genus/species.

2.3 Data preparation

2.3.1 Diversity index choice

Richness (S : number of different taxa) and Simpson's diversity index ($D: 1/\sum P_i^2$, where P_i is the proportional abundance of taxa i) were used to contrasting total number of taxa (richness) to number of abundant taxa at habitat patch level (Jost, 2006). Simpson's evenness ($E: D/S$) was calculated and used as another variable with reference to the proportion of dominant taxa among all taxa. Abundance of all taxa (N) was also added as another information about the community. The four indices are hereinafter referred to as "alpha diversity".

Spatial variation in composition among communities (i.e. beta diversity) was estimated by using the total variance of the site-by-taxa community data (Legendre et al., 2005; Legendre and De Cáceres, 2013). The beta diversity can be partitioned into two matrices representing "replacement" and "richness difference" (Borcard et al., 2018), and each matrix can be analyzed in relation to explanatory environmental variables (Legendre and De Cáceres, 2013). For all types of plant strata and of invertebrates, dissimilarity matrices for beta diversity were built from presence-absence of each taxon in communities because binary dissimilarity coefficients produce more relevant results than quantitative indices when taxa are largely different among communities (Legendre, 2014). The two matrices for replacement and richness difference were hereinafter referred to as "beta diversity".

2.3.2 Calculation of diversity indices and matrices.

Alpha and beta diversity of invertebrates were based upon individuals captured by 68 trap lines for GD invertebrates and 24 yellow pan traps for flying invertebrates. Diversity of plants were measured for each stratum (tree, shrub and herb) based on cover-abundance (m^2) of each species present in an area of 1000 m^2 around trap lines. As pitfalls and yellow pan traps were not precisely set at the same locations, alpha and beta diversity of plants were measured for each type of invertebrate traps. Those areas are hereinafter referred to as "buffers". As the plant inventory was done once between June and September, their presence and relative cover-abundance were considered to be similar at the two seasons for further statistical analysis.

Both alpha diversity and beta diversity were calculated at species level for plants. Calculation of diversity was carried out at family level for invertebrates when available, otherwise at order or class levels (cf. SI Spreadsheet file). Dissimilarity matrix for beta diversity was built using the Jaccard dissimilarity

coefficient and partitioned into matrices for replacement and richness difference, hereinafter referred to as “replacement” and “richness difference”, respectively.

2.3.3 Soil data

Soil properties and soil TM concentrations were referred to Fritsch et al. (2010). As concentrations of Cd, Pb and Zn in soils were highly correlated (Pearson's $r > 0.9$, p-value of correlation test < 0.001), only Pb concentration in soil was used as a proxy of soil TM contamination in our statistical analyses. Soil pH and organic carbon content (g kg^{-1}) in soil, considered as a proxy of the organic matter (OM) content in soils, were used as soil properties importantly related to metal bioavailability (Bradham et al., 2006; Giller et al., 1998; Visioli et al., 2013). Soil pH was also positively correlated with soil TM concentrations (Spearman's $\rho > 0.6$, p-value of correlation test < 0.001 for the three TM). For each buffer, we used soil TM contamination and soil properties of the nearest soil sampling point from the given buffer (i.e. no more than 50 m). Trace metal soil contamination (as represented by Pb soil concentrations), OM content and pH were hereinafter referred to as “Pb”, “pH”, and “OM”, respectively, and linked to each buffer.

2.4 Statistical Analysis

2.4.1 Data transformation

Lead concentrations and OM, as well as abundance (i.e. total cover-abundance of plants or total number of individual invertebrates), were logarithmically transformed because of their skewed distributions. Alpha diversity and the soil variables were then scaled to zero mean and to unit variance for each variable because of their different unit.

2.4.2 Relationships between plant diversity and soil properties

Before assessing the effects of plant diversity on invertebrate communities, the relationship between plant diversity, soil TM contamination and soil properties was explored. Both alpha diversity indices and beta diversity matrices for plants were calculated in vegetation patches near soil sampling points of Fritsch et al. (2010). The analysis used vegetation around 17 soil sampling points, where plants were available for all three strata.

A redundancy analysis (RDA) was executed for the alpha diversity in relation to soil TM contamination and soil properties. A forward selection of significant explanatory variables was carried out (Borcard et al., 2018). Proportion of variance explained by the selected explanatory variables was indicated by an adjusted R^2 (R^2_{adj}) (Peres-Neto et al., 2006). Relationships between plant beta diversity, soil TM contamination and soil properties were assessed by using the distance-based RDA (dbRDA) (Legendre, 2014). Briefly, a principal coordinate analysis (PCoA) was carried out for each dissimilarity matrix after

square-rooted transformation. Their principal coordinates were used as response variables and a forward selection of significant explanatory variables was carried out, and R^2_{adj} was measured. Furthermore, species presence-absence data were *a posteriori* projected on the ordination plot using weighted averages (Borcard et al., 2018), which shows how occurrence of species in communities is affected by the environmental factors analyzed.

2.4.3 Relationships between diversity of invertebrates, diversity of plants and soil properties

The partial RDA (pRDA) and the variation partitioning was applied for invertebrate alpha diversity, using soil TM contamination, soil properties and plant alpha diversity as explanatory variables (Borcard et al., 2018). The pRDA for plant diversity was executed as follows: after RDA for invertebrate alpha diversity data in relation to soil TM contamination and soil properties, the residual variation of this RDA (i.e. variation of invertebrate diversity data non-explained by soil properties) was handled by another RDA in relation with plant alpha diversity. This was *vice versa* for the pRDA in relation to soil properties. Variation explained by selected variables of each explanatory matrix, as well as variation explained jointly by them, were shown using Venn diagram. If one of the two explanatory matrices was not significantly related to the response matrix, ordinal RDA was carried out. The partial dbRDA was applied for invertebrate beta diversity, using soil TM contamination and soil properties and plant alpha diversity as explanatory variables. Invertebrate presence-absence data were then *a posteriori* projected on the ordination obtained.

All statistical analyses and graphics were performed by the statistical software R (ver. 3.6.1; R Development Core Team). PCA, PCoA and RDA were handled with the “vegan” package. The function “forward.sel” of the package “adespatial” was used for forward selection. The functions “beta.div.comp” and “dbRDA.D” from Legendre (2014) were used for building replacement and richness difference dissimilarity matrices and for carrying out accurate significance test for dbRDA, respectively.

3 Results And Discussion

3.1 Plant alpha and beta diversity in relation with soil TM contamination and soil properties

Alpha diversity of plants was not significantly explained by soil TM contamination or soil properties, whatever the plant stratum was. Beta diversity was significantly but weakly explained by soil properties: replacement of tree and herbaceous strata was explained by pH ($R^2_{adj} = 0.052$ and 0.030 , respectively), whereas replacement of shrub stratum was explained by Pb ($R^2_{adj} = 0.055$, for detail see Supporting Information SI Figure 2). Richness difference was not significantly explained by soil TM contamination or soil properties in all plant strata.

According to the ecological indicator value of Landolt et al. (2010) mainly based on plants of the Alpine region, almost all plant species present in low and high metal contaminated buffers show tolerance to soil metal content, referring predominantly to serpentine tolerance (i.e. the tolerance to nickel and chromium), and preference for neutral acidity of soil (Supporting Information SI Figure 2 and SI Table 1). However, most woody patches in our study area showed a high degree of soil anthropization (human density is more than 1000 people per km², Douay et al., 2009). Indeed, some *Salix* sp. and *Populus* sp. specimens, considered as plants for phytoremediation of heavy metal-contaminated soils (Pulford and Watson, 2003), were observed in vegetation patches with both high and low pH and Pb (SI Table 1), which could mean that a large proportion of vegetation cover in our study area has been maintained and/or modified by human management. Thus, effects of soil properties on diversity of vegetation could be biased by anthropogenic factors in our study area. Nonetheless, our results suggest that diversity indices of vegetation can be considered to be virtually independent of soil properties.

3.2 Alpha and beta diversity for ground-dwelling (GD) invertebrates in relation with vegetation and with soil TM contamination and soil properties.

GD invertebrate diversity was more influenced by plant diversity than by soil TM contamination and/or soil properties, but significant relationships varied between season, beta and alpha diversity of invertebrates, and plant strata (Table 2).

In spring, alpha diversity was significantly explained by Simpson's index and abundance of herbs, Pb and OM ($R^2_{adj} = 0.423$). Among the 42.3% of variance, 26.7% was explained only by Simpson's index and abundance of herbs, 8.0% of variance was explained by Pb and OM, and 7.7% were shared by both plant diversity and soil variables (Figure 1a). Controlling for soil variables, richness and abundance of GD invertebrates were negatively correlated with abundance of herbs, whereas evenness was positively correlated with abundance of herbs (Figure 1b). Moreover, Simpson's index of GD invertebrates was negatively correlated with Simpson's index of herbs (Figure 1b). On the other hand, controlling for alpha diversity of plants, Simpson's index and, to a lesser extent, richness of GD invertebrates were positively correlated with Pb (Figure 1c). Evenness was positively correlated with OM, whereas abundance was negatively correlated with OM (Figure 1c). Replacement was significantly but weakly explained by both pH and Simpson's index of shrubs ($R^2_{adj} = 0.068$). Among the 6.8% of variance, 2.6% were explained by pH, 2.3% by Simpson's index of shrubs, and 1.9% were shared by them (Figure 2a). Coleoptera were observed in buffers of both high and low pH or Simpson's index of shrubs. Chilopoda, Opiliones and Glomeridae were present mostly in buffers with low pH, whereas Araneae and Opiliones were observed in buffers with high Simpson's index of shrubs (Supporting Information SI Figure 3 and SI Table 2). Richness difference was significantly explained by the abundance of herbs as well as by Pb and OM ($R^2_{adj} = 0.198$). Among the 19.8% of variance, 7.2% were explained by herb N, 4.0 % were explained by Pb and OM, and 8.7% were shared by them (Figure 2b). Apart from Coleoptera, Arachnida and Glomeridae

were present mostly in buffers with high Pb, whereas numerous taxa such as Chilopoda, Arachnida, Glomeridae, and Polydesmidae were observed in low abundance of herbs (SI Figure 2 and SI Table 2).

In autumn, alpha diversity for GD invertebrates was significantly explained by richness of trees ($R^2_{adj} = 0.125$) but not by soil properties. Evenness was positively correlated with richness of trees, whereas richness, Simpson's index, and abundance of GD invertebrates were negatively correlated with richness of trees (Figure 3). Replacement was significantly explained by OM and pH, and abundance of shrubs ($R^2_{adj} = 0.151$). The two soil properties explained themselves 8.3% of variance, and the rest of the variance (7.3%) was shared with abundance of shrubs (Figure 4). Opiliones, Polydesmidae, Julidae, Isopoda and Formicidae were observed in buffers with high OM and/or high pH (Supporting Information SI Figure 4 and SI Table 3). On the other hand, richness difference was significantly explained by plant diversity richness of trees ($R^2_{adj} = 0.112$), but not by soil properties. Many GD taxa were observed in low richness of trees, such as Araneae, Opiliones, Glomeridae, Polydesmidae, Julidae, Chilopoda, Formicidae, and Coleoptera (SI Figure 4 and SI Table 3).

Our results demonstrate that both alpha and beta diversity of GD invertebrate communities are more explained by plant diversity than by soil TM contamination or some soil properties. The influence of plant diversity, however, largely varied according to plant strata, diversity indices, and seasons. It has been widely reported in both grassland and woodlands that richness and abundance of aboveground invertebrates are positively correlated with richness and abundance of herb layer plants (e.g. Borer et al., 2012; Haddad et al., 2009). Rzanny et al. (2013) and Hertzog et al. (2016) showed more important and direct effects of plant biomass than plant richness on predator arthropods like Carabidae, Staphylinidae or Araneae. Negative correlations we observed between diversity of herbs and GD invertebrates in spring are not in agreement with these studies, Koricheva et al., (2000) observed negative correlation between plant diversity and density of carabid beetles and spiders in an experimental grassland study, though. Moreover, negative effects by grass richness on diversity of predator arthropods was observed in the study of Hertzog et al. (2016), which could be due to low nutritious values of grasses than other plants cascading to communities of herbivores and carnivore (Denno and Fagan, 2003). Communities of arthropod predators strongly depend on plant functional groups and such functional groups were not integrated in our study. Another possible reason is trappability bias due to herb cover. Pitfall traps are effective for capturing highly mobile invertebrates (Uetz and Unzicker, 1976), but their trappability depends on the soil surface, more or less suitable for their movement, and on invertebrates' movement behavior. Complex structure of layer vegetation around pitfall traps could have affected trappability of pitfall traps (Greenslade, 1964; Melbourne, 1999). In autumn, alpha diversity of GD invertebrates was not influenced by tree. In the literature, Schuldt et al. (2011) demonstrated that spider richness and abundance was negatively correlated with tree species richness in forests, which concurs with our result. On the other hand, influence by herb was not observed in autumn. This might be due to several factors. High density or activity of isopods or carabid beetles in spring have been reported (Grelle et al., 2000; Niemelä et al., 1992). Hertzog et al. (2017) observed strong seasonal variation in predation of ground-dwelling predators in an experimental grassland study and attributed it not only to seasonal fluctuation in

their populations but also to change in height of vegetation. In our study, cover-abundance was used as a proxy to the abundance of plants but height of herbs was not considered.

Change in species composition due to different sensitivity to metal contamination among taxa could be one explanation for the relationship between diversity of plants and invertebrate communities. For example, Glomeridae and Polydesmidae are considered to be tolerant to metal pollution due to their high abundance in polluted sites (Read et al., 1998). Abundance of staphylinid beetle was positively correlated with soil Zn content in northern France (Nahmani and Lavelle, 2002). Ants are also considered to be relatively tolerant to metal pollution (Eeva et al., 2004). Isopods are tolerant to soils with higher metal accumulation due to their capability to accumulate metals (Santorufu et al., 2012). Those taxa were observed in buffers with high soil TM contamination and/or low pH (SI Spreadsheet; SI Table 2; SI Table 3). Likewise, change in composition of GD invertebrates along the gradients of vegetation could explain our results. Our results actually showed that shrub diversity explained replacement in GD invertebrate communities. A diversified plant community can provide a variety of resources for herbivore species, which then support prey availability for predators (Hutchinson, 1959; Root, 1973). Schuldt et al. (2008) and Vehviläinen et al. (2008) also argued that the abundance of predatory arthropods like spiders, ants or carabids strongly depends on the presence of specific trees due to several factors such as favorable microclimates, prey abundance or foraging efficiency enhanced by those trees. In our study, phytophagous Curculionidae, saprophagous Aphodiidae, and zoophagous Silphidae, Lampyridae, Staphylinidae, as well as Araneae and Opiliones, were observed in buffers with high Simpson's index of shrubs, whereas saprophagous Forficulidae and polyphagous Elateridae were observed with low Simpson's index of shrubs (diet category on the basis of Jeannel (1941) and Mora (2002); SI Table 2). Furthermore, other abiotic factors also can determine the composition of GD invertebrates, such as temperature, soil moisture, and quality of humus (Koivula et al., 1999; Niemelä et al., 1992; Perner and Malt, 2003; Zimmer et al., 2000; Zimmer and Topp, 2000). Soil pH is also one of the factors determining the composition of GD invertebrates even in unpolluted sites (Schuldt et al., 2011). Communities of GD invertebrates could be indirectly shaped by vegetation that controls these parameters, rather than directly by soil TM contamination and/or soil properties.

3.3 Alpha and beta diversity of flying invertebrates in relation to soil properties and vegetation

Flying invertebrate diversity was influenced by plants but not by soil properties. Only beta diversity, but not alpha diversity, was significantly explained by plant diversity of different strata (Table 2).

In spring, replacement was significantly but weakly explained by richness of shrubs ($R^2_{\text{adj}} = 0.062$). Many taxa were observed in buffers with either high or low richness of shrubs. Moreover, considering the diet of flying invertebrates taxonomic groups according to Jeannel, (1941) and Mora (2002), predator or parasitoid flying invertebrates were more observed in buffers with low richness of shrubs than in buffers with high richness of shrubs (Supporting Information SI Figure 5 and SI Table 4). In autumn, Richness

difference was significantly explained by Simpson's index of trees, evenness of shrubs, and abundance of herbs ($R^2_{\text{adj}} = 0.523$). Many types of diet categories (e.g. zoophagous, saprophagous, phytophagous, opophagous) were observed in buffers where plant diversity indices were high (SI Figure 5 and SI Table 4).

In a recent meta-analysis (Zvereva and Kozlov, 2010), a decrease in population density of epigeic arthropods (e.g. Aranea, Formicidae, Carabidae and Staphylinidae) with increased air pollution (thus not only by TM) was observed, while the density of other arthropod groups, including flying invertebrates, increased. The same meta-analysis also demonstrated that responses of population density to pollution were negative for Arachnida and Coleoptera but positive for Lepidoptera and Hemiptera. Responses to pollutions are likely to differ between ground-dwelling and flying invertebrates.

On the contrary, plant diversity only influenced the composition of flying invertebrates. Based on data about flowering period of woody plants by Landolt et al. (2010), spring was the main flowering period of many trees and shrubs in our study area. Availability of young leaves and flowers of shrubs might mostly draw attention of phytophagous and/or nectarivorous invertebrates. In autumn, diversity indices of many strata were related to beta diversity. Tree species richness in woodland system positively affects richness, diversity and/or abundance of flying invertebrate families like Hymenoptera (Fraser et al., 2007; Sperber et al., 2004) or Diptera (Scherber et al., 2014) due to an increased heterogeneity of structures and availability of resources. Hirao et al. (2009) also showed that lepidopteran community was vertically stratified, which suggests that more vertically diversified habitats might support a more diversified flying invertebrate community. Seasonal difference of diversity of flying invertebrates could be explained, at least partly, by flowering seasons of plants. Furthermore, trapping efficiency by pan traps could also vary among seasons. Rodriguez-Saona et al. (2012) actually demonstrated seasonal change in color preference coinciding with blooming season in blunt-nosed and sharp-nosed leafhoppers (Hemiptera: Cicadellidae). Our results strongly suggest that vegetation shapes the composition of flying invertebrates while environmental metal pollution of soils did not significantly act as a filter.

Limitations Of The Study

With limited duration of invertebrate field investigation, invertebrate community data in this study cannot be considered as a reliable estimation of true diversity and composition of invertebrate communities. Thus our study should be considered as a snapshot evaluation of the separate and combined influences of vegetation, soil characteristics and TM contaminants on invertebrate communities. Another drawback in our results is the variable degree of taxonomic resolution (cf. SI Spreadsheet file), which might have prevented us to find further relationships between invertebrate communities and plant communities or soil contamination or properties.

4 Conclusion

This study sheds light on the effects of plant diversity on diversity and composition of aboveground invertebrate community in a site contaminated by TM. Our results overall indicated that plant diversity shapes community of flying invertebrates and is also a factor controlling both diversity and composition of ground-dwelling invertebrates more importantly than TM contamination and other soil properties do. Although underlying mechanisms about complex correlations between diversity of invertebrates and both diversity of plants and soil properties remain an issue for further studies, our results suggest that soil TM contamination and soil properties did not independently and substantially impact invertebrate communities. This study is, to our knowledge, the first one on a metal polluted ecosystem to actually disentangle the relative importance of two major parameters likely to shape invertebrate communities, plant communities and soil contamination and properties. This will pave the road to the evaluation of contaminant impacts on terrestrial invertebrate community dynamics, and to further insights into pollutant induced community tolerance.

Declarations

Ethics approval and consent to participate

This article does not describe any studies involving human participants performed by the authors. All applicable international, national and/or institutional guidelines for the care and use of animals were followed.

Consent for publication

Not applicable.

Availability of data and materials

Lists of plant and invertebrate species are available on the repository dat@osu (<https://dataosu.obs-besancon.fr/>): <https://doi.org/10.25666/dataosu-2018-07-17>.

Competing interests

The authors declare that they have no conflict of interest.

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Authors' contributions

SO, major contributor in writing the original draft of the manuscript, analyzed and interpreted the data on plant and invertebrate inventory and their spatial distribution. FM performed the invertebrate inventory, whereas TC performed the plant inventory. RS and FR conceptualized this study and acquired the funding. CF, RS and FR supervised the study. All authors read and approved the final manuscript.

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Tables

Table 1. Soil physico-chemical properties and number of buffers sampled in the seven sites.

	TE2	103	117	097	171	043
Soil contamination level	"Control" ^a	Low	Moderate	High	Moderate	Moderate
[Cd] _{soil} (mg kg ⁻¹) ^b Min - Max (Median)	0.9 - 2.4 (1.4)	1.5 - 6.0 (4.3)	3.6 - 17.8 (9.1)	15.3 - 236.5 (48.3)	4.9 - 14.5 (7.5)	1.3 - 42.7 (15.2)
[Pb] _{soil} (mg kg ⁻¹) ^b Min - Max (Median)	43.3 - 199.8 (107.4)	237.5 - 333.0 (267.2)	244.7 - 859.8 (512.0)	658.5 - 6809.4 (1295.3)	287.6 - 2063.3 (584.0)	105.0 - 1028.9 (323.1)
[Zn] _{soil} (mg kg ⁻¹) ^b Min - Max (Median)	89.3 - 277.7 (168.8)	114.4 - 407.5 (352.7)	302.8 - 958.5 (555.8)	1069.3 - 7263.5 (1874.7)	487.2 - 2451.5 (1362.7)	153.9 - 1549.6 (512.8)
pH ^b Min - Max (Median)	4.5 - 7.2 (5.9)	4.6 - 6.9 (5.6)	7.3 - 8.1 (7.9)	7.9 - 8.2 (8.0)	7.7 - 8.3 (8.0)	6.2 - 8.3 (7.0)
OM (g kg ⁻¹) ^b Min - Max (Median)	26.1 - 186.0 (52.6)	47.7 - 96.3 (54.8)	34.3 - 77.3 (60.5)	31.5 - 110.9 (50.5)	35.0 - 223.0 (95.8)	28.5 - 125.4 (57.9)
Number of patches	8	5	4	6	7	7
<i>Trees were present</i>	8	4	3	3	5	7
<i>Shrub were present</i>	7	4	3	3	3	2
<i>Herbs were present</i>	7	3	3	6	6	7
<i>All strata were present</i>	6	3	1	3	2	2
Number of buffers ^c for ground-dwelling-invertebrates	14	15	6	9	14	10
<i>in spring</i>	7	8	2	7	7	5
<i>in autumn</i>	7	7	4	2	7	5
Number of buffers ^c for flying invertebrates	4	5	3	4	4	4

<i>in spring</i>	1	3	1	2	3	2
<i>in autumn</i>	3	2	2	2	1	2

a: TM concentrations as close as possible to background concentrations.

b: Values from Fritsch et al. (2010)

c: Buffers where plants of all strata were present.

Table 2. Plant diversity and soil properties significantly influencing alpha and beta diversity of ground-dwelling (GD) and flying invertebrates.

Type of invertebrates	Season	Type of diversity	Significant influence	
			Plant stratum	Soil properties
GD invertebrates	Spring	<i>Alpha</i>	Herb	Pb, OM
		<i>Beta</i>	Shrub & herb	pH
	Autumn	<i>Alpha</i>	Tree	-
		<i>Beta</i>	Tree & shrub	Pb,
Flying invertebrates	Spring	<i>Alpha</i>	-	-
		<i>Beta</i>	Shrub	-
	Autumn	<i>Alpha</i>	-	-
		<i>Beta</i>	Tree, shrub & herb	-

Figures

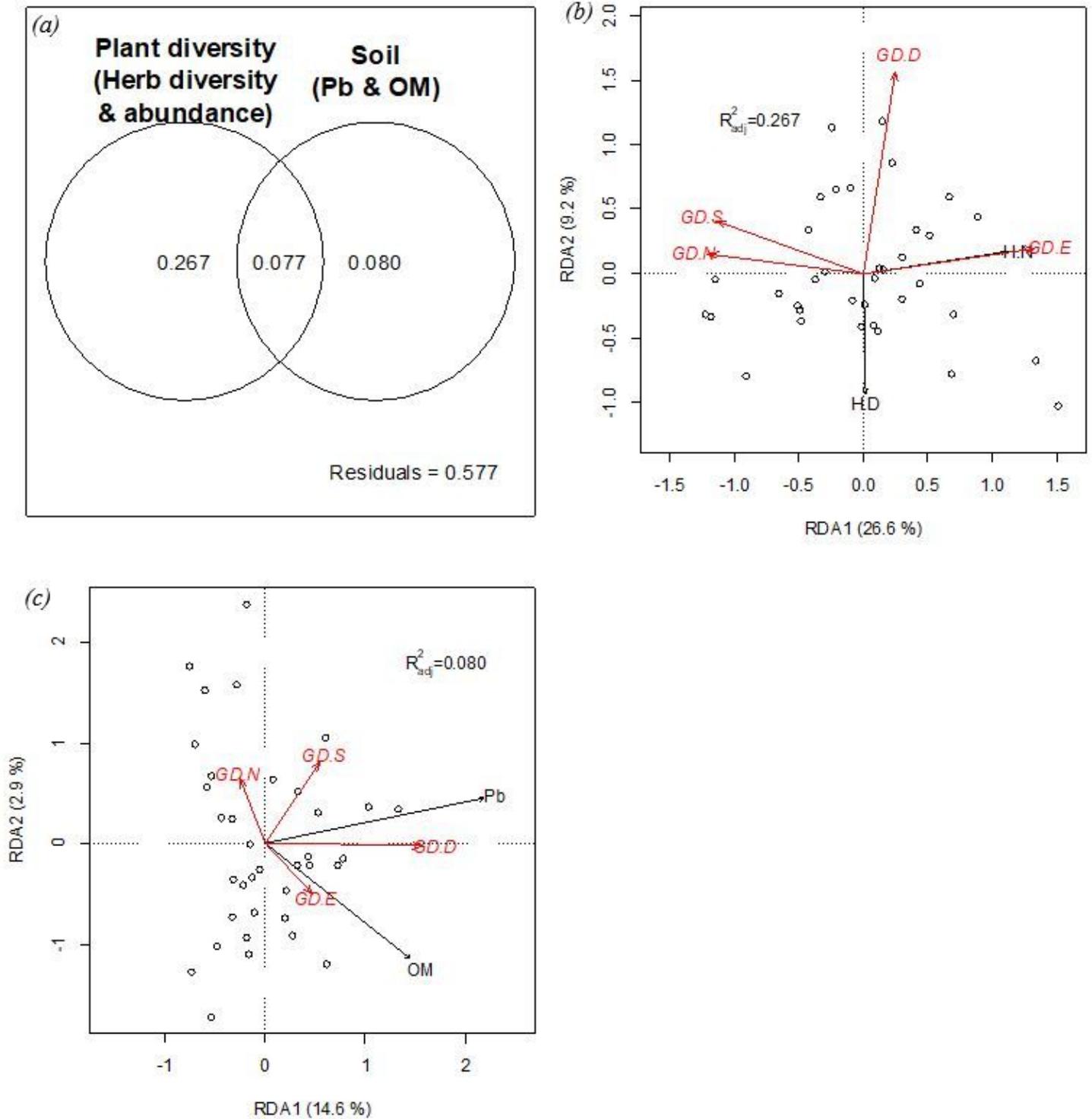


Figure 1

Results of partial redundancy analysis (pRDA) on alpha diversity indices for ground-dwelling (GD) invertebrates in spring. (a) Venn diagram represents variance explained by diversity of plants and soil properties. (b) Biplot of pRDA on invertebrate diversity explained only by plant diversity indices. (c) Biplot of pRDA on invertebrate diversity explained only by soils properties. GD.D, GD.E, GD.N, GD.S: Simpson's diversity index, Simpson's evenness, abundance and richness of GD invertebrates, respectively. H.D, H.N: Simpson's diversity index and abundance of herbaceous stratum, respectively.

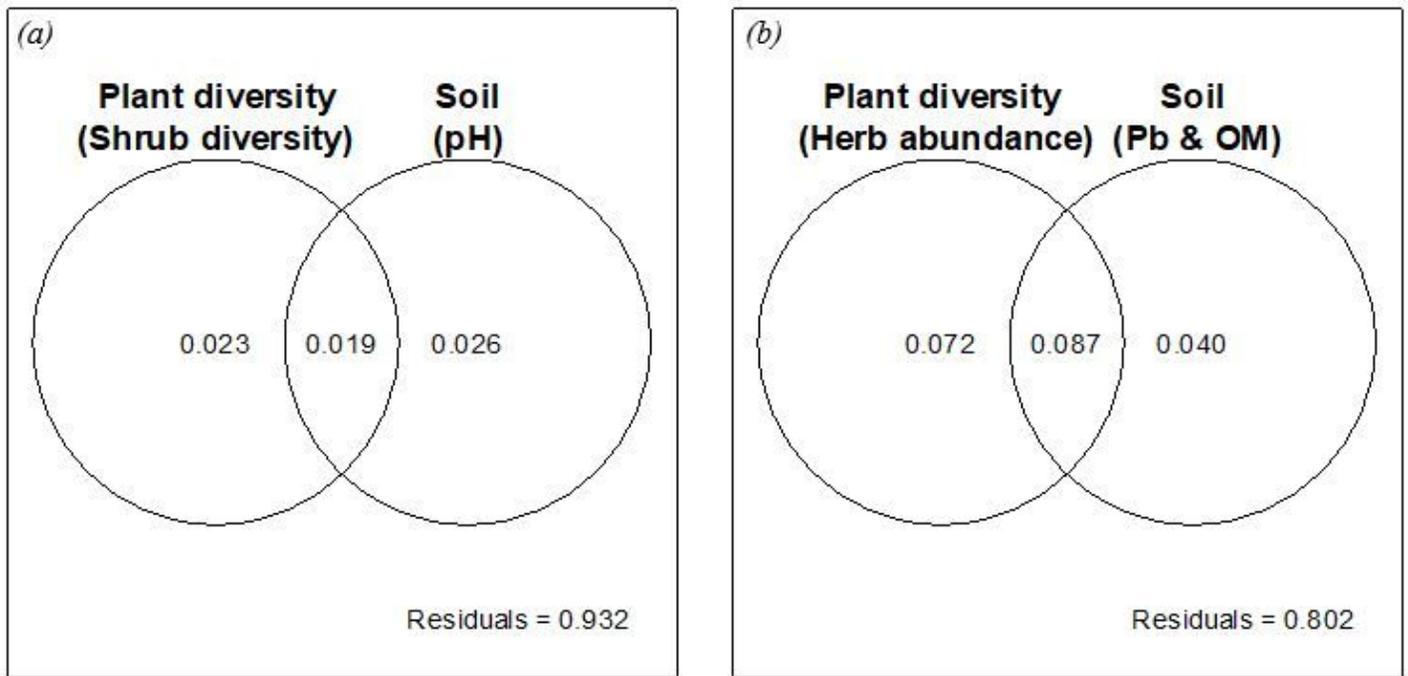


Figure 2

Results of partial distance-based redundancy analysis on beta diversity matrices for GD invertebrates in spring. Venn diagrams represent variance explained by diversity for plants and soil properties for replacement of GD invertebrates in (a) and for richness difference of GD invertebrates in (b).

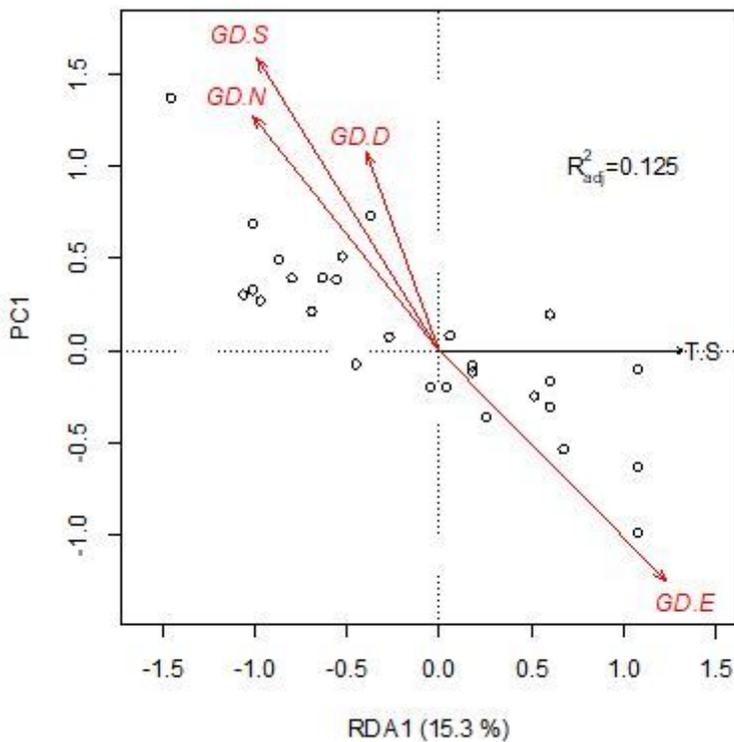


Figure 3

Biplot of redundancy analysis (RDA) on alpha diversity indices for GD invertebrates in autumn. GD.D, GD.E, GD.N, GD.S: Simpson's diversity index, Simpson's evenness, abundance and richness of GD invertebrates, respectively. TS: tree stratum richness.

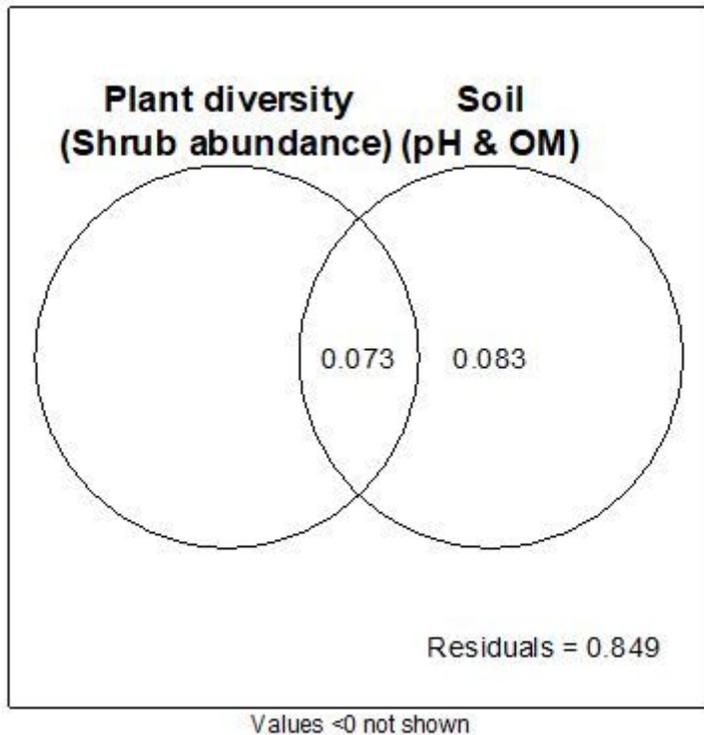


Figure 4

Results of partial distance-based redundancy analysis on replacement of GD invertebrates in autumn. Venn diagram represents variance explained by diversity for plants and soil properties. (N.B. There is no value in the circle for plant diversity because all variance explained by plant diversity was shared with variance explained by soil parameters.)

Supplementary Files

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- [20210413OzakiESPRSI.pdf](#)
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