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Shinji Ozaki, Clémentine Fritsch, Benoît Valot, Frédéric Mora, Renaud Scheifler, et al.. Does pollution influence small mammal diet in the field? A metabarcoding approach in a generalist consumer. *Molecular Ecology*, 2018, 27 (18), pp.3700-3713. 10.1111/mec.14823 . hal-02368039

HAL Id: hal-02368039

<https://hal.science/hal-02368039>

Submitted on 7 Feb 2022

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**Does pollution influence small mammal diet in the field? A metabarcoding approach
in a generalist consumer.**

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19 **Abstract:**

20 Mammals are mainly exposed to trace metals via consuming contaminated food. Several
21 studies have demonstrated relationships between metal concentrations in food and in animal
22 tissues. However, potential effects of trace metals on feeding behaviour of wildlife have been
23 poorly documented under field conditions, despite experimental evidence showing that food
24 selection is impacted by resource contamination. Here we test the hypothesis that the diet of
25 a generalist rodent, the wood mouse (*Apodemus sylvaticus*), is altered by soil trace metal
26 contamination in the field. Wood mice were sampled in spring and in autumn along a
27 gradient of soil contamination in the surroundings of a former smelter located in northern
28 France. Available resources in the field were inventoried and the diet of the animals was
29 analysed using DNA “metabarcoding”. We demonstrated that (i) relationship between the
30 resource richness in the diet and their richness in the field was altered by soil metal
31 contamination. Wood mice specialised their diet along the gradient of soil metal
32 contamination for both plant and invertebrate resources in spring. We also showed that (ii)
33 preference for Salicaceae, a plant family accumulating metals, decreased when soil
34 contamination increased. These results suggest that environmental trace metal pollution
35 could act as a force modulating trophic interactions in terrestrial food webs, thereby affecting
36 wildlife exposure to contaminants by trophic route.

37
38 **Keywords:**

39 Biodiversity; Diet diversity; Food selection; Trace metals; *Apodemus sylvaticus*

Introduction

Feeding behaviour is determined by life history traits and life stages of animals (Schoener, 1971; Pyke et al., 1977), abundance and distribution of food resources in nature (White, 2008; Crampton et al., 2011), and food quality (i.e. nutrient and toxin content) (Butet, 1986a; Kerley & Erasmus 1991; Schmidt, 2000; Lewis et al., 2001). All these factors are driven by ecological determinants like season, climate, community interactions or landscape features (Polis et al., 1997; Visser & Both 2005; White, 2008). The optimal foraging theory assumes that animals consume resources providing high energy intake per unit time (Stephens & Krebs, 1986) and that the diet of animals tends to be specialized when food density is high (MacArthur & Pianka, 1966). However, animals require not only energy but also nutrients like vitamins or essential metals. The nutrient requirements can thus hardly be satisfied from a single plant species and thus animals seek a variety of diet for nutrient balance (i.e. nutrient balance hypothesis) (Westoby, 1978). Likewise, Freeland and Janzen (1974) proposed that generalist mammalian herbivores are unable to detoxify large amounts of similar plant secondary metabolites (i.e. those from a single plant species) and thus a variety of plant sources allow them to avoid similar plant toxin load (i.e. detoxification limitation hypothesis). When the use of a resource is disproportional to its availability in the field, the feeding process by which an animal chooses the resource is called “selection” (Johnson, 1980; Manly et al., 2002). The nature of selection (i.e. preference or avoidance) reflects the likelihood of a given resource for being chosen when this resource is offered with others (Johnson, 1980). The food selection hence manifests a relationship between individual requirements and resource constraints.

Trace metals (TM) are environmental pollutants of concern for both human health and wildlife. They occur often as a legacy of past industrial activities. Even if the emissions of many of them have been reduced in the past decades thanks to environmental regulation and

technical improvements at least in so-called developed countries, the pollution still persists over vast surfaces due to non-degradability of metals and to their current emissions in many countries (Kabata-Pendias, 2011; EMEP, 2013). TM pollution may have effects on plants and invertebrates at several levels of organisation, from sub-individual physiological effects reducing survival or reproduction to the modification of community composition and structure (Walker et al., 2012). For instance, a recent meta-analysis about the responses of terrestrial biota to TM pollution -dealing with 206 pollution point sources worldwide- showed a decrease of diversity for most of the taxa (producers, secondary consumers and decomposers) (Kozlov & Zvereva, 2011). In addition, Dazy et al. (2009) demonstrated that plant species richness correlated negatively to TM concentrations in soils in eastern France. Metal pollution can also reduce species richness in earthworm communities (Spurgeon & Hopkin, 1999; Nahmani et al., 2003) and impact the structure and composition of soil macro-fauna communities (Nahmani & Lavelle, 2002). Trophic transfer , i.e. the transfer of matter via food consumption, is generally considered to be the main route for TM from the environment to animals of higher trophic levels (Shore & Rattner, 2001; Smith et al., 2007). For small mammals, several studies have demonstrated relationships between soil pollution by TM, contamination of food, and subsequently, high concentrations of TM in wild animals' tissues (Hunter & Johnson, 1982; Hunter et al., 1987a; Torres & Johnson, 2001; Rogival et al., 2007; van den Brink et al., 2010). Avoidance of TM contaminated food can be a mechanism that mitigates organisms' exposure to contaminants (Gillet & Ponge, 2003). This has been reported for the wood mouse (*Apodemus sylvaticus*) under laboratory settings but not confirmed in natural conditions (Beernaert et al., 2008). To the best of our knowledge, no study has reported variations of richness in the diet and selection as a response to both the variation of resource availability and the contamination of the environment *in natura* in terrestrial ecosystems.

One of the main difficulties in assessing wildlife diet is the identification of items actually consumed. Identifying items with the highest taxonomic resolution is almost impossible with classical macro- or microscopy-based methods, which then makes it difficult to match diet with field records of resources. Recently, DNA-based techniques have arisen as a powerful approach for the taxonomic identification. Although DNA-based identification is not novel, current technological developments such as DNA metabarcoding approach enable to simultaneously identify different taxa in environmental samples, like soils or faeces, containing multiple specimens and potentially highly degraded DNA (reviewed in Valentini et al., 2009a; Taberlet et al., 2012; Pompanon et al., 2012). The efficiency of this approach for analysing the diet has been demonstrated in various species including herbivorous mammals, birds and invertebrates (Soininen et al., 2009; Valentini et al., 2009b), insectivorous bats (Bohmann et al., 2011), or omnivorous animals like the brown bear (De Barba et al., 2013).

In the present study, we focused on the wood mouse (*Apodemus sylvaticus*), which is a generalist small mammal (Watts, 1968; Hansson, 1985; Butet, 1990) and therefore a model of choice when studying diet plasticity as a response to environmental variations. Indeed, provided its opportunistic feeding behaviour, the diet richness (i.e. total number of resources' species in the diet) of the wood mouse is expected to be positively correlated with resource richness in the field. We hypothesised that: (i) diet richness of the wood mouse would be negatively correlated to TMs contamination of soils given the reported negative effects of pollution on plant and invertebrate richness in community, and (ii) food selection by the wood mouse would be affected by TM contamination in soils possibly due to avoidance behaviour.

Materials and methods

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 surrounding soils were highly contaminated by TM, mainly cadmium (Cd), Pb, and Zn, over a large area of about 120 km² because of metal-contaminated dust released for decades from this smelter and another one named “Umicore”, located about 4 km east of the first (Sterckeman et al., 2002; Douay et al., 2008; Douay et al., 2009; Waterlot et al., 2016). A study area of 40 km² was defined and divided into 160 sites of 25 ha (500m x 500m) (Fritsch et al., 2010), from which seven are used in the present study (see below). Total TM concentrations in the soil of woody patches ranged from 0.1 to 236.5 mg kg⁻¹ of dry soil for Cd, from 16 to 7331 mg kg⁻¹ of dry soil for Pb, and from 44 to 7264 mg kg⁻¹ of dry soil for Zn in an area of 40 km² in the surroundings of the former smelter (Fritsch et al., 2010). These values largely exceed background TM concentrations in soils of the region Hauts-de-France (Sterckeman et al., 2007). Those TM concentrations in woody patches were used in our modelling (cf. below). The seven sites are located along a soil pollution gradient and composed of three types of dominant habitats (woodland, urban features, arable lands) to provide a wide range of resource richness in the field (for details see Supporting Information SII).

Rodent trapping

At each site, we trapped wood mice in spring (April) and in autumn (September and October) 2012 according to Fritsch et al. (2011) and in accordance with current French legislation about ethics and use of animals in research. Briefly, small break-back traps were used with peanut as rodent’s bait. Ten lines, composed of 10 traps 3 m spaced each, were used per site and per season. All trap lines were set in woody habitats of the sites and their location was

geo-referenced. The trap lines were checked in the morning for three consecutive days and re-set and/or re-baited, if necessary. After being weighed in the field, animals were immediately frozen at -20°C for further analyses.

Two hundred and forty-six rodents (117 in spring and 129 in autumn; 116 females and 127 males) were used in the study. Age was estimated using body weight according to four classes (approximately, class I < 50 days < class II < 130 days < class III < 230 days < class IV), referring to Vandorpe & Verhagen (1980) and Tête et al. (2014). Age structure differed between seasons: no mouse of age class I was found in spring, and the proportions of animals in the other 3 classes were significantly different ($\chi^2 = 31.04$, p-value < 0.001) such that animals in spring were older than in autumn.

Stomach content samples

Consumed items were identified by biomolecular analysis of stomach contents (SC). Wood mice were thawed at room temperature. Their SC was extracted from the body with a spatula, which was thoroughly cleaned with disposable tissue, then washed with ultra-pure water (18.2 MΩ/cm²) and wiped off with other tissue between each extraction. Remaining bait was removed from SC. Each SC was then homogenized and split into two aliquots: one (about 10 mg) was stored in 95% ethanol for metabarcoding analysis (see below), the other was reserved for another study. For 13 mice among the 246 rodents, faeces taken from intestines were used as an alternative material for food identification because their stomach was empty. The 13 mice were equitably distributed according to the explanatory factors tested in this study.

Metabarcoding analysis

The DNA extraction, amplification and the PCR purification were performed at SPYGEN

facilities (www.spygen.com). DNeasy Blood and Tissue Kit (Qiagen GmbH) was used for
 extracting total DNA, following the manufacturer's instruction. DNA amplification was
 performed with three sets of primers (Table 1): the P6 loop of the chloroplast *trnL* (UAA)
 intron *g/h* (Taberlet et al., 2007) was used for identifying general plant species; primer
 targeting a short fragment of mitochondrial 16S gene (16S mtDNA) was used for arthropods
 and molluscs DNA (*16SMAV-F/16SMAV-R*) (De Barba et al., 2013); and primer targeting
 short region of 16S mtDNA for earthworms (*ewD/ewE*) (Bienert et al., 2012). PCR
 amplifications were carried out on Applied Biosystems Veriti 96 Wells (Life Technologies).
 The amplification was realized in a final volume of 25 μ L using 3 μ L of DNA extract. Two
 PCR replicates were performed per each sample. For the amplification of arthropod and
 mollusc DNA, 2 μ M of a blocking primer for mammal's DNA (*MamMAVB1*; De Barba et
 al., 2013) was added in the PCR mix. The amplification mixture contained 1 U of AmpliTaq
 Gold DNA Polymerase (Applied Biosystems), 10 mM of Tris-HCl, 50 mM of KCl, 2.5 mM
 of $MgCl_2$, 0.2 mM of each dNTP, 0.2 μ M of group-specific primers, 0.2 μ g/ μ L of bovine
 serum albumin (BSA, Roche Diagnostic) and ultra-pure water (18.2 M Ω /cm²) to bring each
 sample to the final volume. The mixture was denatured at 95°C for 10 min, followed by 45
 cycles of 30 s at 95°C, 30 s at 50°C for *trnL-g/h*, at 55°C for *16SMAV-F/16SMAV-R* and at
 58°C for *ewD/ewE* and 1 min at 72°C, followed by a final elongation at 72°C for 7 min.
 Extraction and PCR negative controls were analysed in parallel in order to monitor potential
 contamination. After amplification, the samples were titrated using capillary electrophoresis
 (QIAxcel; Qiagen GmbH) and purified using a MinElute PCR purification kit (Qiagen
 GmbH). Before sequencing, purified DNA was titrated again using capillary electrophoresis.
 The purified PCR products were pooled in equal volumes, to achieve an expected sequencing
 depth of 10,000 reads per sample. Libraries were prepared using TruSeq Nano DNA genomic
 kit (Illumina) and a pair-end sequencing (2x100 bp) was carried out with an Illumina HiSeq

sequencer (Illumina) using TruSeq SBS Kit v3 (Illumina) following the manufacturer's instructions. Library preparation and sequencing were performed at Fasteris facilities (www.fasteris.com).

Reads were handled by the software Mothur pipeline (Schloss et al., 2009). Briefly, forward and reverse reads were assembled in contig sequences. Then, sequences were filtered based on length (20-90bp for *trnL-g/h*; 36-38bp for *16SMAV*; 69-81bp for *ewD/ewE*), homopolymer (less than 10 nucleotides) and no ambiguous nucleotides. After de-replication (occurrence count of each different sequence), only unique sequences with a minimum count of 10 (sum of all samples) were used for further analysis.

Field inventory of plant and invertebrate resources

Vegetation survey was realized once per site from 4th June to 5th September 2012. Three different strata were defined based on height: tree stratum (woody species > 8 m high), shrub stratum (woody species < 8 m high), and herbaceous stratum. Taxa were identified at species level in the field. Nomenclature of species followed Lambinon et al. (2004) and Dudman & Richards (1997). Cover-abundance of vascular plant species was visually estimated as the vertically projected area following Braun-Blanquet et al. (1952). Vegetation habitats were determined by plants' composition of one or more strata and delineated as polygons with the aid of aerial pictures. The polygons were geo-referenced and digitalized using the QGIS software (<http://www.qgis.org/>). We listed 236 different plant taxa in the field (see SI1 for the taxonomic richness in the field per site and SI2 for the list of the taxa and their abundance per site).

Invertebrate fauna was sampled at the same time as the rodent trapping (i.e. in the two seasons). Ground-dwelling invertebrates were captured near rodent traps using three pitfall traps per line. Flying invertebrates were captured with yellow pan traps containing a mix of

soap and water. Four yellow pan traps were set in each site. Yellow colour attracts especially flower visiting insects. The traps were checked every morning for three consecutive days. All traps were geo-referenced. Captured invertebrates were conserved in ethanol or in freezer at -20°C and identified to the highest possible taxonomic resolution by morphological characteristics (the main references are Coulon, 2003; Forel & Leplat, 2001; Jeannel, 1941; Trautner & Geigenmueller, 1987). Captured ground-dwelling and flying invertebrates consisted of 88 and 95 taxa, respectively (see SI1 for the taxonomic richness in the field per site and SI2 for the list of the taxa and their abundance per site). Because of the different taxonomic resolution, we used mainly family level (and higher levels) for invertebrate richness in the field (cf below): 24 and 95 families (or higher) in ground-dwelling and flying invertebrates, respectively.

We then estimated available resources for wood mice near their trapping location. Although notion of “availability” is distinct from “abundance” in selection studies (Manly et al., 2002), we considered them equivalent for wood mice given its generalist diet behaviour. Plant resource availability was estimated by the cover-abundance of each plant species found within a buffer of 10 m around trap lines (referred to as “buffer” thereafter). This buffer is equivalent to an area of about 1000 m², considered as the average size of wood mouse vital domain (Quéré & Le Louarn, 2011). We considered the data set collected between June and September to be representative of food availability in spring and autumn. Since the traps used to capture invertebrates (pitfall trap and yellow pan trap) were inappropriate for catching earthworms and molluscs, both earthworm and mollusc richness in the field were unknown. Resource availability of ground-dwelling invertebrates in buffers both in spring and in autumn was estimated by the abundance of each taxa found per trap line (sum of the three traps per line), whereas availability of flying invertebrates was based on abundance in the yellow pan trap nearest to the trap line.

Diet diversity analyses

Sequence data for diet diversity analyses

Diet diversity analyses were performed by employing Molecular Operational Taxonomic Units (MOTUs): groups of DNA sequences clustered according to similarity, which are thus independent of any reference database (Sun et al., 2012). Sequences were clustered for each primer with average neighbour algorithm using Needlman-Wunsch distance. Distances cutting clusters were arbitrarily chosen as 0.032 for sequences obtained from primer *trnL-g/h*, as 0.042 for *16SMAV* and as 0.034 for *ewD/ewE* (see SI3 for sequence data of plant, arthropod and earthworm MOTUs). Deagle et al. (2013) showed that the number of sequences obtained from degraded DNA is likely not proportional to the biomass of each taxa really eaten. The quantitative sequence information data were therefore converted into presence/absence of MOTUs using an occurrence threshold of 100 to remove background sequencing data.

Diet richness and modelling

Richness in the diet of each mouse was calculated as the total number of MOTUs per mouse by three types of food: plant, arthropod and mollusc (referred to as “arthropod” thereafter), or earthworm. We assumed that plants potentially consumed by the invertebrates would not artificially increase the number of plant MOTUs consumed by the rodent (i.e. there may be no secondary predation, for detail see Harwood et al., 2001) because the number of plant MOTUs was not significantly different between SCs containing or not containing invertebrate food (arthropod and/or earthworm) (data not shown). The diet richness per mouse was compared among seasons, wood mouse sexes and age-classes, and landscape features using the nonparametric Wilcoxon-Mann-Whitney (for comparison of two

categories) or Kruskal-Wallis tests (for more than two categories), due to skewed distribution of MOTUs data. Frequency of occurrence was also compared by chi-square goodness-of-fit test.

Relationship between diet richness, richness in the field and TM concentrations in soil was assessed by statistical modelling. In order to estimate the richness in the diet of all mice in a buffer, the total number of MOTUs of all mice captured over a given buffer (referred to as “diet richness” thereafter) was calculated, per type of food or as total diet richness by summing plant, arthropod and earthworm MOTUs. The relationship was analysed using multimodel inference on the basis of the information-theoretic approaches (Burnham & Anderson, 2002). A set of candidate models was established by combinations of several explanatory variables. Second order Akaike Information Criterion (AICc: corrected AIC for small sample size in relation to the number of model parameters) was used for ranking the proposed models. Probability of the “best” model over the set was estimated by Akaike weight (w). In situations where the best model was uncertain (i.e. w of the first ranked model < 0.9), we applied a model averaging approach for reducing model selection uncertainty. A confidence set of candidate models, whose $\Delta AICc < 6$ (difference of AICc from the first ranked model < 6 , which is equivalent to a likelihood ratio from the first ranked model > 0.05), was re-selected, and each parameter of those re-proposed models was averaged by re-calculated Akaike weight (Burnham & Anderson, 2002). When a given parameter was not included in a proposed model, the value of the parameter was considered as 0 in this model (Burnham & Anderson, 2002; Lukacs et al., 2010).

All candidate models were established as generalized linear models (GLM) with logarithm link function for Poisson distribution. Models were built separately per season, given potential seasonal diet variation of the animal (Butet, 1986b; Abt & Bock, 1998), as well as per TM, considering their different effects on organisms and transfer pathways (Eisler, 2000).

We used the diet richness in buffer as response variable and number of analysed mice per trap line as one of the explanatory variables. Soil TM concentrations of woody patch characterised by Fritsch et al. (2010) were applied to buffer set in or near a given woody patch. Mice of age class I were discarded from modelling because diet of juveniles could differ from adults (Watts, 1968; Montgomery & Montgomery, 1990). The modelling was carried out on 38 buffers in spring and 37 buffers in autumn. Number of mice used in the analysis was 181 and their number per line ranged from 1 to 6.

For plant richness in the diet, combinations of three variables and one interaction were considered as candidate models: number of mice, TM concentrations in soils of woody habitat (referred by the data of Fritsch et al., 2010; see "Study site" above) with a natural logarithm transformation, and plant richness in the field, as well as an interaction between the TM concentrations and the plant richness in the field (i.e. 10 models including the intercept only model). For arthropod richness in the diet, four variables and two interactions were used: mouse number, TM concentrations, both ground-dwelling and flying invertebrate richness in the field, as well as two interactions between the TM concentration and the richness in the field (i.e. 26 models). For earthworm richness in the diet, we used only two variables: mouse number and TM concentrations (i.e. four models). For total diet richness, we used three variables and one interaction: mouse number, TM concentrations, and total richness in the field (sum of plant and both ground-dwelling and flying invertebrate richness at family level), as well as interaction between the TM concentrations and the total richness in the field (i.e. 10 models). Overdispersion (observed variance higher than theoretical one) was checked according to Cameron & Trivedi (1990). Explanatory value of our final models were estimated by deviance R^2 (R^2_D : proportion of deviance explained by the given model) (Zuur, 2009).

Food selection analyses

Sequence data for selection analysis and association with field survey data

Reference sequences of the species recorded in our study area were taken from the GenBank sequence database (www.ncbi.nlm.nih.gov/genbank). Each sequence extracted from SCs (i.e., query sequence) was compared to the reference sequences for checking their similarity, where we accepted difference of only one nucleotide. When query sequences could match with several reference sequences, they were gathered into one group composed of the corresponding species, called “sequence group (Grp)” (see SI4 for details of sequence groups). Non assigned query sequences were excluded. Query sequences with occurrence lower than 100 were not considered. Food Grp data were finally converted into presence/absence. We represented Grps using both ID number and family name(s) corresponding to their component species. We applied such method only to plant food because almost all invertebrate resources in the field were identified to family level only.

Plant food selection and modelling

Frequency of occurrence of each plant food item (i.e. percentage of number of occurrences of a given item compared to the total number of occurrence of all items, referring to Klare et al., 2011) was calculated at family level using Grp. Food selection was assessed, for each plant food item, per season, comparing the frequency of occurrence and relative proportion of resources in the field (i.e. cover-abundance of a given plant food of all strata compared to the total cover-abundance of all plants of all strata). Plant resource taxa in the field were gathered into corresponding Grp and then into the same plant family. Resource availability was estimated based on the abundance of the plant families in each buffer, summed up per family for all mice in each season. Significance of food selection was evaluated per plant family using Bailey’s confidence intervals at $p\text{-value} < 0.05$ (Bailey, 1980; Cherry, 1996):

when relative availability of a given resource was located below or above the confidence interval of its frequency of occurrence, this resource is considered as preferred or avoided, respectively.

Preference change according to richness in the field and/or TM concentrations in soil was then assessed by multimodel inference approaches. First, food selection was estimated in each buffer as described above. Buffers where selection for a given resource was observed were considered 1 (i.e. selection for the resource is present), whereas the other buffers were considered 0 (i.e. selection for the resource is absent). We used GLM with logit link function for assessing change of proportion of buffers where preference was observed. There were only one plant family (Salicaceae) for which selection was significantly observed in more than five buffers, allowing statistical analyses. Salicaceae was preferred in spring in six among 38 buffers. Candidate models were established by combinations of three variables and one interaction: mice number in buffer, plant richness in the field, and TM concentrations, as well as an interaction between the richness in the field and the TM concentrations. The modelling was performed for each TM. Model selection methods were the same as described above.

All statistical analyses were computed using the statistical software R (ver. 3.4.2; R Development Core Team). GLM was handled by “glm” function in “lme4” package and model averaging by “model.avg” function in “MuMIn” package. Overdispersion checking was carried out by “dispersiontest” function in “AER” package.

Results

Resources richness in the field, trace metals and diet richness

Plant items occurred in the diet of 96.3% of wood mice, arthropod items in 65.9% and earthworm items in 29.3%. The occurrence of earthworm items was significantly lower in

forest landscape and significantly higher in urban landscape ($\chi^2 = 7.619$, p-value = 0.022; for details see SI5). The variations of the total richness in the diet and of the relative proportion of the three food item categories (plants, arthropods and earthworms) along the soil contamination gradient are shown in SI6 and SI7, respectively.

Number of plant MOTUs per mouse ranged from 0 to 7 and median was 2 MOTUs. It was significantly higher in autumn than in spring ($W = 5394.5$, p-value < 0.001). Number of arthropod MOTUs ranged from 0 to 9 and median was 1 MOTUs. In autumn, the number was significantly lower in age class I than in class II (Kruskal-Wallis $\chi^2 = 7.972$, p-value = 0.047) (N.B. no mouse of class I was found in spring). Number of earthworm MOTUs ranged from 0 to 3 and median was 0 MOTUs. The number was significantly higher in urban area than in forest area in spring only (Kruskal-Wallis $\chi^2 = 8.068$, p-value = 0.018) (see SI8).

No single “best” model was evidenced and thus model averaging was applied for all sets of models. Complete results of modelling are shown in SI9. The final model for plant richness in the diet in buffer included mouse number, soil TM concentrations, richness in the field and the interaction between the last two for the three TM in the two seasons. Figure 1a and 1b show plant richness in the diet according to plant richness in the field and Cd concentration in soils in spring, respectively. The pattern was similar for the other metals. Influence of richness in the field on the diet richness was tiny in spring (Figure 1a), whereas diet richness decreased according to TM in soils regardless of the richness in the field (e.g. from 6 to 4 plant MOTUs along the range of TM concentration; Figure 1b). R^2_D was 0.301, 0.313 and 0.307 for Cd, Pb and Zn, respectively. Such tendency changed in autumn (Figure 1c and 1d for Cd, similar for other TM). Diet richness was negatively correlated to plant richness when soil contamination was low, while this correlation disappeared, or even reversed, when TM concentration increased (Figure 1c). A similar tendency was predicted for the relationship between diet richness and TM contamination in soils (Figure 1d): diet

richness was negatively correlated to TM concentration when plant richness was low and positively correlated when the plant richness was high. R^2_D was 0.624, 0.492 and 0.601 for Cd, Pb and Zn, respectively.

The model for invertebrate richness in the diet included all proposed explanatory variables in the two seasons, except the interaction between TMs in soils and richness of ground-dwelling invertebrates for the models for Cd and Zn in autumn. In spring, arthropod richness in the diet increased according to richness of both ground-dwelling and flying invertebrates when soil contamination was low. This correlation disappeared, then reversed, when TM concentration in soils increased. For example, our model for Cd predicted that arthropod MOTUs increased from 2 to 5 along the gradient of ground-dwelling invertebrate richness in the field when Cd concentration in soils was low, whereas arthropod MOTUs decreased from 5 to 3 when Cd concentration was high (Figure 2a; the pattern was similar for flying invertebrates). The relationship between arthropod richness in the diet and TM concentration in soils followed the same tendency (Figure 2b). In autumn, arthropod richness in the diet was explained almost only by mouse number. Neither TM concentration in soils nor richness of both types of invertebrates had sensible influence on diet richness (Figure 2c and 2d). R^2_D for Cd, Pb and Zn was respectively 0.502, 0.472 and 0.495 in spring, and 0.495, 0.504 and 0.497 in autumn.

The averaging model for earthworm richness in the diet included mouse number and TM concentrations in soils in both seasons. Earthworm richness in the diet slightly decreased along TM gradient (e.g. difference of about 0.5 MOTUs; Figure 3a and 3b), and mouse number on trap line had a larger influence in autumn than in spring. R^2_D for Cd, Pb and Zn was respectively 0.101, 0.056 and 0.075 in spring, and 0.169, 0.158, 0.192 in autumn.

Plant food selection

We found 48 Grps in the food of the 246 mice. Sapindaceae, Salicaceae, Cornaceae, Adoxaceae, Asteraceae, and Rosaceae were plant taxa frequently eaten in our area (see SI10 for details). Selection for some plant families was observed at the scale of all study sites together and at the two seasons: preference for Fagaceae and avoidance of Urticaceae. Furthermore, selected plant resources changed between the two seasons, for example preference for Salicaceae, Sapindaceae and Rosaceae in spring and preference for Poaceae, Adoxaceae, Asteraceae and Cornaceae in autumn (see SI11 for details). Model averaging was used for the final model for Salicaceae preference in spring (see SI12 for complete results). The model included all variables: mouse number, plant richness in the field, TM concentration in soils and the interaction. Preference for Salicaceae was negatively correlated to plant richness in the field when soil contamination was low (e.g. from 0.6 to 0.4; Figure 4a). On the other hand, preference for Salicaceae disappeared along the gradient of TM concentration in soils, whatever plant richness in the field was (e.g. preference probability for Salicaceae decreased from 0.6 to 0; Figure 4b). R^2_D of the final model was 0.280, 0.165 and 0.271 for Cd, Pb and Zn, respectively.

Discussion

We first hypothesised that soil TM contamination would reduce diet richness of wood mouse due to adverse effect of TM on resources' richness in the field. Our study revealed negative correlations between diet richness and TM in soils. This was true for both earthworms and plants in spring and in autumn (although only at low and medium levels of plant richness in autumn), and for arthropods in spring when richness in the field was high. On the contrary, positive correlations were observed, for plants in autumn when plant richness in the field was high, and for arthropods in spring when arthropod richness in the field was low. A negative relationship between diet richness and pollution by TM is expected if resource

richness in the field is negatively affected by TM concentrations. Literature about the effects of pollution on various taxonomic groups suggests a global negative effect of pollution on the richness of organisms, and an absence or a positive correlation for a few taxa groups or situations. Although decreasing richness of earthworms with increasing TM concentrations gradients in soils has been widely reported (Spurgeon & Hopkin, 1996, Spurgeon & Hopkin, 1999; Pérès et al., 2011), several studies have reported that relationships between species richness of soil macro-fauna and TM contamination is not straightforward (Nahmani & Lavelle, 2002; Gillet & Ponge, 2003; Migliorini, et al., 2004). Moreover, several studies showed that community composition was affected by soil TM concentrations. Tolerance to, and/or accumulation capacity of metals differ according to taxa, organs, and metals (Das et al., 1997; Broadley et al., 2007; Pourrut et al., 2011). Lower resistance to toxic effects can make metal sensitive plants disappear in contaminated areas, which may favour metal tolerant ones, sometimes without modification of taxonomic richness. Such modification of community composition has been reported by several authors in plants (Banášová et al., 2006; Strandberg et al., 2006; Dazy et al., 2009) and in invertebrates (Nahmani & Lavelle, 2002; Migliorini et al., 2004; Babin-Fenske & Anand, 2011). In our study area, we found no correlation or even positive trends between TM concentration in soils and both plant and invertebrate richness in the field (unpublished data). However, there were confounding factors in our site like the anthropogenic increase of habitat diversity (see Douay et al., 2009) and possibly of plant richness along the gradient of contamination on the Metaleurop Nord site. Community composition also differed according to soil contamination levels or other soil properties affecting metal bioavailability (unpublished data). Difference in resource composition could alter resource availability and thus modify feeding behaviour and diet composition. Few studies documented the effects of pollution on the diet of terrestrial vertebrates, most of them dealing with diet composition rather than richness or diversity.

Clare et al. (2014), describing the diet of insectivorous bats *Myotis lucifugus* in different locations, showed a trend of lower diet species richness in area of lower habitat quality (acidification or organic pollution). Eeva et al. (2005) showed a significant difference in diet composition of nestlings of two insectivorous birds, *Parus major* and *Ficedula hypoleuca*, between unpolluted and TM polluted sites, reflecting differences in resources composition, phenology and feeding ecology among the two bird species: in polluted areas where caterpillars were less abundant, both species ate more beetles and different larvae of flying insects but less moth. The study of Heroldová (2002) demonstrated that the diet of field vole *Microtus agrestis* in forest clearings caused by air pollution was dominated by grasses, reflecting higher abundance of grasses and a poorer diversity of food supply in clearings. Thus, it is suggested that diet richness (as demonstrated in the present study) and/or composition can be affected by pollution induced changes in trophic resources.

We also hypothesized that TM contamination would affect food selection by wood mouse. Our model predicts that preference probability for Salicaceae in spring in the highest contaminated sites decreases to become almost null. Avoidance of TM contaminated soil or food has been shown in invertebrates but has rarely been investigated in vertebrates, and is particularly hard to prove under field conditions in comparison with controlled experiments. This behaviour has been observed under laboratory conditions for some invertebrates like isopods or small moths (Odendaal & Reinecke, 1999; Zidar et al., 2004; Scheirs et al., 2006), and for the wood mouse (Beernaert et al., 2008), but mechanisms of such aversion are not yet elucidated. In Beernaert et al. (2008), wood mice chose acorns (*Quercus robur*, Fagaceae) sampled from unpolluted sites rather than ones from metal polluted sites (mainly by Cd, copper, Pb, and Zn), but such avoidance behaviour was no longer detected under field conditions, perhaps due to ecological co-factors such as food shortage, and/or the presence of competitors and predators. Avoidance of contaminated food, leading to shifts in diet, can

be one of the mechanisms allowing animals to mitigate their exposure in highly polluted environments (Gillet & Ponge, 2003). Actually, Salicaceae family is considered as TM accumulator and resistant to highly TM contaminated soils (Pulford & Watson, 2003). Migeon et al. (2009) showed that Salicaceae family in the surroundings of Metaleurop Nord, composed of two genera *Salix* and *Populus*, accumulated larger amount of Cd and Zn in their shoot parts than the other families like Fagaceae or Sapindaceae. These two last are also preferred plant families in our study and known as common food of wood mice (i.e. Watts, 1968). However, mechanisms of changes in preference remains unclear. The nutritional quality of metal contaminated plant organs has been shown to be lowered, with for instance a decrease of sugar or protein concentrations (Scheirs et al., 2006; Beernaert et al., 2008), features which play an important role for food choice in rodents (Butet, 1990; Kerley & Erasmus, 1991). It is also possible that animals might identify metal contaminated plants due to metal-induced metabolic compounds (Poschenrieder et al., 2006), largely known as compounds limiting feeding (Foley & Moore, 2005). Dearing et al (2000) reported that plant secondary compounds might play more important role than nutrient level in the diet of the generalist woodrat, *Neotoma albigula*. It is therefore supposed that mice could directly or indirectly detect noxious substances (plant toxins or TM) and avoid ingesting such items. Also, Behmer et al. (2005) demonstrated from their experiments using nutritionally balanced synthetic food that high Zn concentration *per se* altered the feeding behaviour of the desert locust *Schistocerca gregaria*. Whatever the mechanism, the hyperaccumulation of metals in plant tissues contribute to defensive effects of plants against natural enemies, including invertebrate herbivory (Poschenrieder et al., 2006; Boyd, 2007). Such defensive effect has not been reported against vertebrates so far, but the disappearance of the preference for Salicaceae family along TM contamination in soils could be associated to its high metal accumulation capacity. Furthermore, plant richness in the diet in autumn increased along the

soil TM concentration gradient when richness in the field was high. Apart from changes of resource composition, this pattern could be explained, at least partly, by the nutrient balance hypothesis or the detoxification limitation hypothesis: if nutritional quality of all plant resources was altered (i.e. if nutritional quality was not clearly contrasted among resources) diet richness of animals could increase for completing nutrient and/or for avoiding loads of similar secondary compounds.

Contrary to plants, selection for invertebrate food could not be analysed in part because of the primer used for arthropods and molluscs: its short size is more reliable for the analysis of degraded DNA in the case of diet (Taberlet et al., 2012) but the precision in taxonomic assignment was low. We also did not sample earthworms in the field. Moreover, it is difficult to determine selection for invertebrate resources because of their mobility. Foraging strategy of predators can be modified according to mobility of preys (Sih & Christensen, 2001), suggesting that relative quantity in the field is not the only factor to consider when analysing mobile prey selection. Even though we supposed that decreased earthworm diet richness might be linked to their richness in the field, invertebrate food selection in wood mice remains as a further challenge.

An important feature of our results is the strong seasonal difference of patterns, for both food selection and correlations with TM contamination. In temperate ecosystems, seasons have a key influence on the dynamics of ecosystems and on the various aspects of biology and ecology of living organisms. Seasonal difference of patterns might result from the adaptation of wood mice feeding behaviour to phenology of resources. Indeed, wood mice consume mainly seeds and other reproductive organs (Watts, 1968; Butet, 1986a), seeking high energy or protein-rich tissues (Butet, 1990). Although parts of plant resources actually consumed could not be distinguished by using DNA metabarcoding, we supposed that parts of plants preferably consumed have changed between spring and autumn. Moreover, the nutritional

composition and quality of plants and invertebrates are likely to vary according to seasons. Also, resources functionally important for wood mice might have a strong phenology, such as mushrooms in autumn. However, the molecular primers we used did not target mushrooms, which prevents further conclusion. Finally, TM accumulation in organisms is also subject to seasonality at contaminated site (i.e. Hunter et al, 1987b; Migeon et al., 2009). Seasonal variation of TM accumulation pattern can be related to growth season or physiological changes of each taxa (Kabata-Pendias, 2011; Hussein et al., 2006). Disentangling the combined effects of these factors on the patterns of interest in this study is beyond our present scope, but it is clear that seasonality is a key feature of the interplay between pollution, resource dynamics and consumer feeding behaviour.

Our study sheds light on the effects of soil TM contamination on patterns of feeding behaviour of a generalist consumer, by applying DNA metabarcoding for diet identification. We underline potential altering effects of TM on the diet richness, which possibly partly results from modifying food selection, at least for plant resources. Such modification of diet related to habitat contamination might lead to a different pattern of contaminant exposure in the animals. We hence suggest that ecosystem pollution should now be considered as a driver of changes in food web structure and dynamics in time and space.

Acknowledgements

This study was financially supported by the project BIOTROPH, co-funded by the *Agence De l'Environnement et de la Maîtrise de l'Energie* (ADEME; contract No.1172C0030) and the *Conseil Régional du Nord-Pas de Calais* (CRNPC; orders No.12000921 and 14001044; joint call with the *Fondation pour la Recherche sur la Biodiversité*). The first author was also financially supported by a grant from the *Conseil Régional de Franche-Comté* (contract No. 2015C-06107). The authors gratefully thank Cécile Grand from ADEME for fruitful

566 scientific discussions. We also thank Eva Bellemain and Alice Valentini from SPYGEN
567 Company for their help in DNA analyses and interpretation. We finally thank François Gillet,
568 Nadia Crini, Dominique Rieffel and Anne-Sophie Prudent for their precious assistance.

References:

- Abt, K. F., & Bock, W. F. (1998). Seasonal variations of diet composition in farmland field mice *Apodemus* spp. and bank voles *Clethrionomys glareolus*. *Acta Theriologica*, 43, 379–389.
- Babin-Fenske, J., & Anand, M. (2011). Patterns of insect communities along a stress gradient following decommissioning of a Cu–Ni smelter. *Environmental Pollution*, 159, 3036–3043.
- Bailey, B. J. R. (1980). Large sample simultaneous confidence intervals for the multinomial probabilities based on transformation of the cell frequencies. *Technometrics*, 22, 583–589.
- Banásová, V., Horak, O., Čiamporová, M., Nadubinská, M., & Lichtscheidl, I. (2006). The vegetation of metalliferous and non-metalliferous grasslands in two former mine regions in Central Slovakia. *Biologia*, 61, 433–439.
- Beernaert, J., Scheirs, J., Van Den Brande, G., Leirs, H., Blust, R., De Meulenaer, B., ... Verhagen, R. (2008). Do wood mice (*Apodemus sylvaticus* L.) use food selection as a means to reduce heavy metal intake? *Environmental Pollution*, 151, 599–607.
- Behmer, S. T., Lloyd, C. M., Raubenheimer, D., Stewart-Clark, J., Knight, J., Leighton, R. S., ... Smith, J. A. C. (2005). Metal hyperaccumulation in plants: mechanisms of defence against insect herbivores. *Functional Ecology*, 19, 55–66.
- Bienert, F., De Danieli, S., Miquel, C., Coissac, E., Poillot, C., Brun, J.-J., & Taberlet, P. (2012). Tracking earthworm communities from soil DNA. *Molecular Ecology*, 21, 2017–2030.
- Bohmann, K., Monadjem, A., Lehmkuhl Noer, C., Rasmussen, M., Zeale, M. R. K., Clare, E., ... Gilbert, M. T. P. (2011). Molecular Diet Analysis of Two African Free-Tailed Bats (Molossidae) Using High Throughput Sequencing. *PLoS ONE*, 6, e21441.

- 595 Boyd, R. S. (2007). The defense hypothesis of elemental hyperaccumulation: status,
596 challenges and new directions. *Plant and Soil*, 293, 153–176.
- 597 Braun-Blanquet, J., Roussine, N., & Nègre, R. (1952). *Les groupements végétaux de la*
598 *France méditerranéenne*. CNRS: Direction de la Carte des Groupements Végétaux
599 de l'Afrique du Nord.
- 600 Broadley, M. R., White, P. J., Hammond, J. P., Zelko, I., & Lux, A. (2007). Zinc in plants.
601 *New Phytologist*, 173, 677–702.
- 602 Burnham, K. P., & Anderson, D. R. (2002). *Model selection and multimodel inference: a*
603 *practical information-theoretic approach* (2nd ed). New York: Springer.
- 604 Butet, A. (1986a). Régime alimentaire d'une population de mulots sylvestres (*Apodemus*
605 *sylvaticus* L., 1758), dans une lande xéro-mésophile en cours de recolonisation
606 végétale. *Bulletin D'Ecologie*, 17, 21–37.
- 607 Butet, A. (1986b). Stratégie d'utilisation et déterminisme des choix alimentaires d'un
608 rongeur polyphage (*Apodemus sylvaticus*, L.): l'approche énergétique. *Acta*
609 *Oecologica*, 7, 243–262.
- 610 Butet, A. (1990). Teneur azotée des ressources et choix trophiques du Mulot sylvestre
611 (*Apodemus sylvaticus*) dans un système oligotrophe. *Canadian Journal of Zoology*,
612 68, 26–31.
- 613 Cameron, A. C., & Trivedi, P. K. (1990). Regression-based Tests for Overdispersion in the
614 Poisson Model. *Journal of Econometrics*, 46, 347–364.
- 615 Cherry, S. (1996). A comparison of confidence interval methods for habitat use-availability
616 studies. *The Journal of Wildlife Management*, 60, 653–658.
- 617 Clare, E. L., Symondson, W. O. C., Broders, H., Fabianek, F., Fraser, E. E., MacKenzie, A.,
618 ... Reimer, J. P. (2014). The diet of *Myotis lucifugus* across Canada: assessing
619 foraging quality and diet variability. *Molecular Ecology*, 23, 3618–3632.

- 620 Coulon, J. (2003). Les Bembidiina de la faune de France. Clés d'identification commentées
621 (Coleoptera Carabidae Trechinae) (Première partie). *Bulletin mensuel de la Société*
622 *linnéenne de Lyon*, 72, 256–272.
- 623 Crampton, L. H., Longland, W. S., Murphy, D. D., & Sedinger, J. S. (2011). Food abundance
624 determines distribution and density of a frugivorous bird across seasons. *Oikos*, 120,
625 65–76.
- 626 Das, P., Samantaray, S., & Rout, G. R. (1997). Studies on cadmium toxicity in plants: a
627 review. *Environmental Pollution*, 98, 29–36.
- 628 Dazy, M., Béraud, E., Cotelle, S., Grévillet, F., Férard, J.-F., & Masfaraud, J.-F. (2009).
629 Changes in plant communities along soil pollution gradients: Responses of leaf
630 antioxidant enzyme activities and phytochelatin contents. *Chemosphere*, 77, 376–
631 383.
- 632 De Barba, M., Miquel, C., Boyer, F., Mercier, C., Rioux, D., Coissac, E., & Taberlet, P.
633 (2013). DNA metabarcoding multiplexing and validation of data accuracy for diet
634 assessment: application to omnivorous diet. *Molecular Ecology Resources*, 14, 306–
635 323.
- 636 Deagle, B. E., Thomas, A. C., Shaffer, A. K., Trites, A. W., & Jarman, S. N. (2013).
637 Quantifying sequence proportions in a DNA-based diet study using Ion Torrent
638 amplicon sequencing: which counts count? *Molecular Ecology Resources*, 13, 620–
639 633.
- 640 Dearing, M. D., Mangione, A. M., & Karasov, W. H. (2000). Diet breadth of mammalian
641 herbivores: nutrient versus detoxification constraints. *Oecologia*, 123, 397–405.
- 642 Douay, F., Pruvot, C., Waterlot, C., Fritsch, C., Fourier, H., Loriette, A., ... Scheifler, R.
643 (2009). Contamination of woody habitat soils around a former lead smelter in the
644 North of France. *Science of The Total Environment*, 407, 5564–5577.

- 645 Douay, F., Pruvot, C., Roussel, H., Ciesielski, H., Fourrier, H., Proix, N., & Waterlot, C.
646 (2008). Contamination of Urban Soils in an Area of Northern France Polluted by
647 Dust Emissions of Two Smelters. *Water, Air, and Soil Pollution*, 188, 247–260.
- 648 Dudman, A. A., & Richards, A. J. (1997). *Dandelions of Great Britain and Ireland*,
649 *Handbook 9*. London: Botanical Society of the British Isles.
- 650 Eeva, T., Ryömä, M., & Riihimäki, J. (2005). Pollution-related changes in diets of two
651 insectivorous passerines. *Oecologia*, 145, 629–639.
- 652 Eisler, R. (2000). *Handbook of chemical risk assessment: health hazards to humans, plants*,
653 *and animals. Volume 1, metals*. Boca Raton, Florida: Lewis.
- 654 EMEP (2013). *Long term Changes of Heavy Metal Transboundary Pollution of the*
655 *Environment (1990-2010)* (No. 2/2013).
- 656 Foley, W. J., & Moore, B. D. (2005). Plant secondary metabolites and vertebrate herbivores
657 – from physiological regulation to ecosystem function. *Current Opinion in Plant*
658 *Biology*, 8, 430–435.
- 659 Forel, J., & Leplat, J. (2001). *Faune des carabiques de France* (Vol. 1). Magellanes.
- 660 Freeland, W. J., & Janzen, D. H. (1974). Strategies in herbivory by mammals: the role of
661 plant secondary compounds. *The American Naturalist*, 108, 269–289.
- 662 Fritsch, C., Cœurdassier, M., Giraudoux, P., Raoul, F., Douay, F., Rieffel, D., ... Scheifler,
663 R. (2011). Spatially Explicit Analysis of Metal Transfer to Biota: Influence of Soil
664 Contamination and Landscape. *PLoS ONE*, 6, e20682.
- 665 Fritsch, C., Giraudoux, P., Cœurdassier, M., Douay, F., Raoul, F., Pruvot, C., ... Scheifler, R.
666 (2010). Spatial distribution of metals in smelter-impacted soils of woody habitats:
667 Influence of landscape and soil properties, and risk for wildlife. *Chemosphere*, 81,
668 141–155.
- 669 Gillet, S., & Ponge, J.-F. (2003). Changes in species assemblages and diets of Collembola

670 along a gradient of metal pollution. *Applied Soil Ecology*, 22, 127–138.

671 Hansson, L. (1985). The food of bank voles, wood mice and yellow-necked mice.

672 *Symposium of the Zoological Society of London*, 55, 141–168.

673 Harwood, J. D., Phillips, S. W., Sunderland, K. D., & Symondson, W. O. C. (2001).

674 Secondary predation: quantification of food chain errors in an aphid–spider–carabid

675 system using monoclonal antibodies. *Molecular Ecology*, 10, 2049–2057.

676 Heroldová, M. (2002). Food selection of *Microtus agrestis* in air-pollution affected clearings

677 in the Beskydy Mts, Czech Republic. *Folia Zoologica*, 51, 83–91.

678 Hunter, B. A., & Johnson, M. S. (1982). Food chain relationships of copper and cadmium in

679 contaminated grassland ecosystems. *Oikos*, 38, 108–117.

680 Hunter, B. A., Johnson, M. S., & Thompson, D. J. (1987a). Ecotoxicology of copper and

681 cadmium in a contaminated grassland ecosystem III. Small mammals. *Journal of*

682 *Applied Ecology*, 24, 601–614.

683 Hunter, B. A., Johnson, M. S., & Thompson, D. J. (1987b). Ecotoxicology of copper and

684 cadmium in a contaminated grassland ecosystem II. Invertebrates. *Journal of Applied*

685 *Ecology*, 24, 587–599.

686 Hussein, M. A., Obuid-Allah, A. H., Mohammad, A. H., Scott-Fordsmand, J. J., & Abd El-

687 Wakeil, K. F. (2006). Seasonal variation in heavy metal accumulation in subtropical

688 population of the terrestrial isopod, *Porcellio laevis*. *Ecotoxicology and*

689 *Environmental Safety*, 63, 168–174.

690 Jeannel, R. (1941). *Coléoptères carabiques*. Paris: Librairie de la faculté des sciences.

691 Johnson, D. H. (1980). The Comparison of Usage and Availability Measurements for

692 Evaluating Resource Preference. *Ecology*, 61, 65–71.

693 Kabata-Pendias, A. (2011). *Trace elements in soils and plants* (4th ed). Boca Raton: CRC

694 Press.

- 695 Kerley, G. I. H., & Erasmus, T. (1991). What do mice select for in seeds? *Oecologia*, 86,
696 261–267.
- 697 Klare, U., Kamler, J. F., & Macdonald, D. W. (2011). A comparison and critique of different
698 scat-analysis methods for determining carnivore diet: Comparison of scat-analysis
699 methods. *Mammal Review*, 41, 294–312.
- 700 Kozlov, M. V., & Zvereva, E. L. (2011). A second life for old data: Global patterns in
701 pollution ecology revealed from published observational studies. *Environmental*
702 *Pollution*, 159, 1067–1075.
- 703 Lambinon, J., Delvosalle, L., & Duvigneaud, J. (2004). *Nouvelle flore de la Belgique, du*
704 *Grand-Duché de Luxembourg, du Nord de la France et des Régions voisines* (5th ed).
705 Meise: Jardin botanique national de Belgique.
- 706 Lewis, C. E., Clark, T. W., & Derting, T. L. (2001). Food selection by the white-footed mouse
707 (*Peromyscus leucopus*) on the basis of energy and protein contents. *Canadian*
708 *Journal of Zoology*, 79, 562–568.
- 709 Lukacs, P. M., Burnham, K. P., & Anderson, D. R. (2010). Model selection bias and
710 Freedman’s paradox. *Annals of the Institute of Statistical Mathematics*, 62, 117–125.
- 711 MacArthur, R. H., & Pianka, E. R. (1966). On optimal use of a patchy environment. *The*
712 *American Naturalist*, 100, 603–609.
- 713 Manly, B. F. L., McDonald, L., Thomas, D., McDonald, T. L., & Erickson, W. P. (2002).
714 *Resource selection by animals: statistical design and analysis for field studies* (2nd
715 ed). Dordrecht: Kluwer Academic.
- 716 Migeon, A., Richaud, P., Guinet, F., Chalot, M., & Blaudez, D. (2009). Metal Accumulation
717 by Woody Species on Contaminated Sites in the North of France. *Water, Air, and Soil*
718 *Pollution*, 204, 89–101.
- 719 Migliorini, M., Pigino, G., Bianchi, N., Bernini, F., & Leonzio, C. (2004). The effects of

720 heavy metal contamination on the soil arthropod community of a shooting range.
 721 *Environmental Pollution*, 129,

722 Montgomery, S. S. J., & Montgomery, W. I. (1990). Intrapopulation variation in the diet of
 723 the wood mouse *Apodemus sylvaticus*. *Journal of Zoology*, 222, 641–651.

724 Nahmani, J., & Lavelle, P. (2002). Effects of heavy metal pollution on soil macrofauna in a
 725 grassland of Northern France. *European Journal of Soil Biology*, 38, 297–300.

726 Nahmani, J., Lavelle, P., Lapied, E., & van Oort, F. (2003). Effects of heavy metal soil
 727 pollution on earthworm communities in the north of France: The 7th international
 728 symposium on earthworm ecology· Cardiff· Wales· 2002. *Pedobiologia*, 47, 663–
 729 669.

730 Odendaal, J. P., & Reinecke, A. J. (1999). Short-Term Toxicological Effects of Cadmium on
 731 the Woodlouse, *Porcellio laevis* (Crustacea, Isopoda). *Ecotoxicology and*
 732 *Environmental Safety*, 43, 30–34.

733 Pérès, G., Vandenbulcke, F., Guernion, M., Hedde, M., Beguiristain, T., Douay, F., ...
 734 Cluzeau, D. (2011). Earthworm indicators as tools for soil monitoring,
 735 characterization and risk assessment. An example from the national Bioindicator
 736 programme (France). *Pedobiologia*, 54S, S77–S87.

737 Polis, G. A., Anderson, W. B., & Holt, R. D. (1997). Toward an integration of landscape and
 738 food web ecology: the dynamics of spatially subsidized food webs. *Annual Review*
 739 *of Ecology and Systematics*, 28, 289–316.

740 Pompanon, F., Deagle, B. E., Symondson, W. O. C., Brown, D. S., Jarman, S. N., & Taberlet,
 741 P. (2012). Who is eating what: diet assessment using next generation sequencing.
 742 *Molecular Ecology*, 21, 1931–1950.

743 Poschenrieder, C., Tolrà, R., & Barceló, J. (2006). Can metals defend plants against biotic
 744 stress? *Trends in Plant Science*, 11, 288–295.

745 Pourrut, B., Shahid, M., Dumat, C., Winterton, P., & Pinelli, E. (2011). Lead Uptake, Toxicity,
 746 and Detoxification in Plants. *Reviews of Environmental Contamination and*
 747 *Toxicology*, 213, 113–136.

748 Pulford, I. D., & Watson, C. (2003). Phytoremediation of heavy metal-contaminated land by
 749 trees—a review. *Environment International*, 29, 529–540.

750 Pyke, G. H., Pulliam, H. R., & Charnov, E. L. (1977). Optimal foraging: a selective review
 751 of theory and tests. *Quarterly Review of Biology*, 52, 137–154.

752 Quéré, J.-P., & Le Louarn, H. (2011). *Les rongeurs de France : Faunistique et biologie* (2nd
 753 ed). Versailles: Quae.

754 Rogival, D., Scheirs, J., & Blust, R. (2007). Transfer and accumulation of metals in a soil–
 755 diet–wood mouse food chain along a metal pollution gradient. *Environmental*
 756 *Pollution*, 145, 516–528.

757 Scheirs, J., Vandevyvere, I., Wollaert, K., Blust, R., & De Bruyn, L. (2006). Plant-mediated
 758 effects of heavy metal pollution on host choice of a grass miner. *Environmental*
 759 *Pollution*, 143, 138–145.

760 Schloss, P. D., Westcott, S. L., Ryabin, T., Hall, J. R., Hartmann, M., Hollister, E. B., ...
 761 Weber, C. F. (2009). Introducing mothur: Open-Source, Platform-Independent,
 762 Community-Supported Software for Describing and Comparing Microbial
 763 Communities. *Applied and Environmental Microbiology*, 75, 7537–7541.

764 Schmidt, K. A. (2000). Interactions between food chemistry and predation risk in fox
 765 squirrels. *Ecology*, 81, 2077–2085.

766 Schoener, T. W. (1971). Theory of feeding strategies. *Annual Review of Ecology and*
 767 *Systematics*, 2, 369–404.

768 Shore, R. F., & Rattner, B. A. (2001). *Ecotoxicology of Wild Mammals*. New York: John
 769 Wiley and Sons.

770 Sih, A., & Christensen, B. (2001). Optimal diet theory: when does it work, and when and
771 why does it fail? *Animal Behaviour*, 61, 379–390.

772 Smith, P. N., Cobb, G. P., Godard-Coddling, C., Hoff, D., McMurry, S. T., Rainwater, T. R.,
773 & Reynolds, K. D. (2007). Contaminant exposure in terrestrial vertebrates.
774 *Environmental Pollution*, 150, 41–64.

775 Soininen, E. M., Valentini, A., Coissac, E., Miquel, C., Gielly, L., Brochmann, C., ...
776 Taberlet, P. (2009). Analysing diet of small herbivores: the efficiency of DNA
777 barcoding coupled with high-throughput pyrosequencing for deciphering the
778 composition of complex plant mixtures. *Frontiers in Zoology*, 6, 16.

779 Spurgeon, D. J., & Hopkin, S. P. (1996). The effects of metal contamination on earthworm
780 populations. *Applied Soil Ecology*, 4, 147–160.

781 Spurgeon, D. J., & Hopkin, S. P. (1999). Seasonal variation in the abundance, biomass and
782 biodiversity of earthworms in soils contaminated with metal emissions from a
783 primary smelting works. *Journal of Applied Ecology*, 36, 173–183.

784 Stephens, D. W., & Krebs, J. R. (1986). *Foraging Theory* (Princeton University Press).
785 Princeton, New Jersey.

786 Sterckeman, T., Douay, F., Fourrier, H., & Proix, N. (2007). Référentiel pédo-géochimique
787 du Nord-Pas de Calais. *Conseil Régional Du Nord-Pas de Calais*.

788 Sterckeman, T., Douay, F., Proix, N., Fourrier, H., & Perdrix, E. (2002). Assessment of the
789 contamination of cultivated soils by eighteen trace elements around smelters in the
790 North of France. *Water, Air, and Soil Pollution*, 135, 173–194.

791 Strandberg, B., Axelsen, J. A., Pedersen, M. B., Jensen, J., & Attrill, M. J. (2006). Effect of
792 a copper gradient on plant community structure. *Environmental Toxicology and*
793 *Chemistry*, 25, 743–753.

794 Sun, Y., Cai, Y., Huse, S. M., Knight, R., Farmerie, W. G., Wang, X., & Mai, V. (2012). A

795 large-scale benchmark study of existing algorithms for taxonomy-independent
796 microbial community analysis. *Briefings in Bioinformatics*, 13, 107–121.

797 Taberlet, P., Coissac, E., Pompanon, F., Gielly, L., Miquel, C., Valentini, A., ... Willerslev,
798 E. (2007). Power and limitations of the chloroplast *trnL* (UAA) intron for plant DNA
799 barcoding. *Nucleic Acids Research*, 35(3), e14.

800 Taberlet, P., Coissac, E., Hajibabaei, M., & Rieseberg, L. H. (2012). Environmental DNA.
801 *Molecular Ecology*, 21, 1789–1793.

802 Tête, N., Afonso, E., Crini, N., Drouhot, S., Prudent, A.-S., & Scheifler, R. (2014). Hair as a
803 noninvasive tool for risk assessment: Do the concentrations of cadmium and lead in
804 the hair of wood mice (*Apodemus sylvaticus*) reflect internal concentrations?
805 *Ecotoxicology and Environmental Safety*, 108, 233–241.

806 Torres, K. C., & Johnson, M. L. (2001). Bioaccumulation of metals in plants, arthropods,
807 and mice at a seasonal wetland. *Environmental Toxicology and Chemistry*, 20, 2617–
808 2626.

809 Trautner, J., & Geigenmueller, K. (1987). *Tiger Beetles, Ground Beetles (Illustrated Key to*
810 *the Cicindelidae and Carabidae of Europe)*. Aichtal: Joseph Margraf.

811 Valentini, A., Pompanon, F., & Taberlet, P. (2009a). DNA barcoding for ecologists. *Trends*
812 *in Ecology & Evolution*, 24, 110–117.

813 Valentini, A., Miquel, C., Nawaz, M. A., Bellemain, E., Coissac, E., Pompanon, F., ...
814 Taberlet, P. (2009b). New perspectives in diet analysis based on DNA barcoding and
815 parallel pyrosequencing: the *trnL* approach. *Molecular Ecology Resources*, 9, 51–60.

816 van den Brink, N., Lammertsma, D., Dimmers, W., Boerwinkel, M.-C., & van der Hout, A.
817 (2010). Effects of soil properties on food web accumulation of heavy metals to the
818 wood mouse (*Apodemus sylvaticus*). *Environmental Pollution*, 158, 245–251.

819 Vandorpe, E., & Verhagen, R. (1980). An age reference model for the Wood mouse

- 820 *Apodemus sylvaticus* (Linnaeus, 1758), by use of the lens technique. *Annales de La*
821 *Société Royale Zoologique de Belgique*, 109, 133–140.
- 822 Visser, M. E., & Both, C. (2005). Shifts in phenology due to global climate change: the need
823 for a yardstick. *Proceedings of the Royal Society B: Biological Sciences*, 272, 2561–
824 2569.
- 825 Walker, C. H., Hopkin, S. P., Sibly, R. M., & Peakall, D. B. (2012). *Principles of*
826 *Ecotoxicology* (4th ed). Boca Raton: CRC Press.
- 827 Waterlot, C., Pruvot, C., Bidar, G., Fritsch, C., De Vaufléury, A., Scheifler, R., & Douay, F.
828 (2016). Prediction of Extractable Cd, Pb and Zn in Contaminated Woody Habitat
829 Soils Using a Change Point Detection Method. *Pedosphere*, 26, 282–298.
- 830 Watts, C. H. S. (1968). The Foods Eaten by Wood Mice (*Apodemus sylvaticus*) and Bank
831 Voles (*Clethrionomys glareolus*) in Wytham Woods, Berkshire. *Journal of Animal*
832 *Ecology*, 37, 25–41.
- 833 Westoby, M. (1978). What are the biological bases of varied diets? *The American Naturalist*,
834 112, 627–631.
- 835 White, T. C. R. (2008). The role of food, weather and climate in limiting the abundance of
836 animals. *Biological Reviews*, 83, 227–248.
- 837 Zidar, P., Drobne, D., Štrus, J., Van Gestel, C. A. M., & Donker, M. (2004). Food selection
838 as a means of Cu intake reduction in the terrestrial isopod *Porcellio scaber* (Crustacea,
839 Isopoda). *Applied Soil Ecology*, 25, 257–265.
- 840 Zuur, A. F. (2009). *Mixed effects models and extensions in ecology with R*. New York:
841 Springer.

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843 **Data Accessibility:**

844 DNA sequence data, soil TM concentration in buffers, resources availability in buffers, and
845 wood mouse data are available from the metadata portal “dat@osu”;
846 doi:10.25666/DATAOSU-2018-07-17.

Supporting Information:

- SI1: Information for each study site about TM contamination and dominant landscape feature, as well as richness of plants and invertebrates observed in the field.
- SI2: Inventory of plant and invertebrate taxa observed in each site.
- SI3: Sequence data of plant, arthropod and earthworm MOTUs for each mouse.
- SI4: Sequence data of sequence groups for each mouse.
- SI5: Frequency of occurrence of plant, arthropod and earthworm items in wood mouse food across several environmental and biological factors.
- SI6: Variation of the total richness in the diet along the soil contamination gradient.
- SI7: Relative proportion of the three food item categories (plants, arthropods and earthworms) along the soil contamination gradient.
- SI8: Plant, arthropod and earthworm richness in the diet of wood mouse across several environmental and biological factors.
- SI9: Complete data on models of richness in the diet.
- SI10: Complete data on number and frequency of occurrence of plant food item (sequence group).
- SI11: Information on food selection for plant families corresponding to sequence groups in the wood mouse in spring and in autumn.
- SI12: Complete results on plant food selection modelling at buffer scale.

Author contributions:

F.R. and R.S. conceived the study; S.O., R.S., C.F. and F.R. designed the study; R.S., C.F., F.M., T.C. and F.R. performed field samplings and laboratory treatments; B.V. performed bioinformatics treatments; S.O. performed the statistical analyses; S.O., F.R., R.S. and C.F. interpreted the results. S.O. wrote the manuscript under the supervision of F.R., R.S. and C.F.

874 *Table 1: Characteristics of the three primers used to amplify wood mouse stomach content DNA samples.*
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Taxonomic group	DNA type	DNA region	Primer name	Primer sequence 5'-3'	Reference
Plants	Chloroplast	trnL (UAA)	g (<i>forward</i>) h (<i>reverse</i>)	GGGCAATCCTGAGCCAA CCATTGAGTCTCTGCACCTATC	Taberlet <i>et al.</i> , 2007
Arthropods & molluscs	Mitochondrial	16S mtDNA	16SMAV-F 16SMAV-R	CCAACATCGAGGTCRYAA ARTTACYNTAGGGATAACAG	De Barba <i>et al.</i> , 2013
Earthworms	Mitochondrial	16S mtDNA	ewD (<i>forward</i>) ewE (<i>reverse</i>)	ATTCGGTTGGGGCGACC CTGTTATCCCTAAGGTAGCTT	Bienert <i>et al.</i> , 2012

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Figure 1: Plant richness in the diet of the wood mouse along the gradient of plant richness in the field and Cd concentration in soils, in spring (a and b) and in autumn (c and d). Each point represents a buffer and point size is proportional to the number of mice captured in a given buffer. Values predicted from models are indicated by three lines: dotted, normal and bold lines correspond to minimal, median and maximum value of Cd concentration in soils (a and c) or plants richness in the field (b and d), respectively. The number of mice is fixed to the median value for drawing the lines (three mice in spring and two mice in autumn). The patterns are similar for Pb and Zn concentrations in soils.

Figure 2: Invertebrate richness in the diet of the wood mouse along the gradient of ground-dwelling invertebrate richness in the field and Cd concentration in soils in spring (a and b) and in autumn (c and d). Each point represents a buffer and point size is proportional to the number of mice captured in a given buffer. Values predicted from models are indicated by three lines: dotted, normal and bold lines correspond to minimal, median and maximum value of Cd concentration in soils (a and c) or ground-dwelling invertebrate richness in the field (b and d), respectively. Mouse number is fixed to the median value for drawing the lines (three mice in spring and two mice in autumn). The patterns of the relation between ground-dwelling invertebrate richness in the diet and in the field are similar for flying invertebrate richness. The patterns are similar for Pb and Zn concentrations in soils.

Figure 3: Earthworm richness in the diet of the wood mouse along the gradient of Cd concentration in soils in spring (a) and in autumn (b). Each point represents a buffer and point size is proportional to the number of mice captured in a given buffer. Values predicted from our model are indicated by a line. Mouse number is fixed to the median value for drawing the line (three mice in spring and two mice in autumn). The patterns are similar for Pb and Zn concentrations in soils.

Figure 4: Predicted probabilities of preference for Salicaceae in spring along the gradient of plant richness in the field (a) and Cd concentration in soils (b). Plotted points at probability value 1 indicate buffers where preference for Salicaceae was observed, and points at 0 indicate buffers where preference was not observed. Predicted probability from our model is indicated by three lines: dotted, normal and bold lines correspond minimal, median and maximum value of Cd concentrations in soils (a) or plant richness in the field (b), respectively. Mouse number is fixed to the median value for drawing the lines (three mice in spring and two mice in autumn). The patterns are similar for Pb and Zn concentrations in soils.