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Research paper

Initial conditions during Technosol implementation shape earthworms and ants diversity

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HIGHLIGHTS

- Technosols, made of backfills, provide habitats recolonized by soil macrofauna.
- Ants and earthworms communities were composed of few ubiquitous species.
- Their abundances increased with the age of Technosols with initial topsoil addition.
- Their abundances decreased with age without initial topsoil addition.
- Proportion of green spaces in the landscape does not affect diversity.

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ABSTRACT

Soils in urban parks are mainly manmade and called Technosols. These Technosols are made of backfill with or without a topsoil addition, which may affect both the physicochemical properties of these soils and the success of soil fauna colonization. The effects of these initial soil management conditions on colonization dynamics of Technosols have not been evaluated yet.

To fill this gap, we sampled earthworms and ants in 20 Technosols covered by lawn and located in urban parks around Paris (France). We selected Technosols constructed with or without an initial addition of topsoil and distributed along an age gradient since construction ranging from 2 to 64 years. Surrounding greening index around Technosols, management practices and physicochemical soil properties have also been recorded.

Surprisingly, no significant differences were observed in the physicochemical properties of Technosols regardless of the absence/presence of topsoil. Communities were composed of few ubiquitous species, which could explain the lack of species richness response to any of our variables. Earthworm and ant abundances increased significantly along the age gradient only in Technosols with initial addition of topsoil. In Technosols, initial conditions apparently determine in part soil macrofauna.

Thanks to a close collaboration between scientist and managers, we highlighted that managers should add topsoil during the creation of Technosols in order to sustain abundance of ecosystem engineers and potentially the ecosystem services they provide.

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1. Introduction

The surfaces covered by urban areas are expected to increase by 70% from 2000 to 2030 in Europe and will double by 2050, reaching 7% of emerged earth surfaces (UNFPA, 2011). Urbanization causes profound impacts on ecosystem functioning (Pickett et al., 2011) but the consequences for urban soil ecosystem processes are not well documented (De Kimpe and Morel, 2000; Pouyat et al., 2010) despite their importance in the delivery of ecosystem services (Morel, Chenu, & Lorenz, 2015). Urban soils can be highly heterogeneous and are mainly affected by human activities (Morel et al., 2015). The soils in urban parks contain a significant amount of recently excavated earth from deep soil horizons and other man made materials such as bricks or crushed stones (used as backfill) (IUSS Working Group WRB, 2006). Because of the importance of human disturbance in excavating this material, the soil of urban parks belongs to the Technosols Reference Soil Group (IUSS Working Group WRB, 2006). Their management is a growing concern (De Kimpe & Morel, 2000).

Currently, the demand to increase the number and the surface area of parks in cities is strong (Clergeau, 2007). This involves the construction of new Technosols as backfills from urban materials such as excavated deep soils or building pieces. In some cases, an initial input of organic matter, consisting in initial topsoil coverage on backfills, is added, which is supposed to help the development of the planted vegetation. However, topsoil is mainly retrieved from rural areas to urban areas (Cheverry & Gascuel, 2009), with high economic and environmental costs related to transportation and degradation of rural ecosystems. An alternative is to avoid topsoil coverage by planting vegetation directly on backfills. The impact of this initial management decision on soil biodiversity has never been addressed.

Soil macrofauna (animal organisms larger than 2 mm, Lavelle et al., 2006) is poorly understood (Decaëns, 2010) even though it provides numerous soil ecosystem services (Bardgett & van der Putten, 2014). Soil macrofauna contains two main ecosystem engineers (sensu Jones, Lawton, & Shachak, 1994): ants (Hexapoda Formicidae) and earthworms (Annelida Lumbricidae). They are involved in many ecosystems processes (Blouin et al., 2013; Lobry De Bruyn & Conacher, 1990) that affect in nutrient cycling, soil formation, soil structure maintenance, primary production, pollution remediation and water and climate regulation. However, their structure and function in urban soils remains poorly known (but see Pouyat et al., 2010; Vepsäläinen, Ikonen, & Koivula, 2008).

As reviewed by Walker, Wardle, Bardgett, & Clarkson (2010), many authors considered that initial abiotic conditions may affect soil properties and processes with soil fauna effects along an age gradient (chronosequence). Excavated deep soil lacks macrofauna and topsoil may lose them as a result of disturbance (Séré et al., 2008). These new initial conditions may affect the success of colonization by macrofauna. Colonization processes along an age gradient coupled with various initial conditions, which are also management decisions, have not been studied in Technosols. To fill this gap, we sampled earthworms and ants in Technosols with or without an initial addition of topsoil and along an age gradient from 2 to 64 years.

This study aims to identify factors influencing Technosols colonization by ants and earthworms and their community build-up by taking into account landscape properties such as the proximity of other greenspaces or roads and local (soil physicochemical characteristics and lawn management practices) that could affect species survival. We expected (H1) an increase of abundance/density and diversity along the age gradient, (H2) a stronger positive effect in Technosols with the initial presence of topsoil and (H3) a positive effect of the proximity of other greenspaces.

2. Material and methods

2.1. Study sites and sampling design

The study area is located in the Seine-Saint-Denis and Val-de-Marne districts, which are located around Paris city and are among the most urbanized districts of France, with urbanization rates around 60% (Fig. 1) and human densities around 6000 inhabs km^{-2} (IAU îDF, 2013). The climate is temperate and the substratum is mainly made of carbonated rocks of the Parisian Basin (France) from the Eocene (Antoni et al., 2013).

The sampling took place in urban parks managed by the Seine-Saint-Denis (Fig. 2) and Val-de-Marne (Fig. 3) districts. A single urban park is generally composed of a series of Technosols that are highly-heterogeneous in term of land use, vegetation type, age since construction, initial conditions and type of urban soils (Morel et al., 2015).We limited our study to recreational lawn (hereafter lawn) dominated by grasses (*Lolium perenne*, *Festuca spps and Poa spps*) and with past agricultural uses (as market gardens).

We sampled two types of initial conditions of Technosols, with or without facultative initial topsoil covering on mineral backfill, here after referred as topsoil presence/absence. We sampled 12 Technosols with initial topsoil and 8 without initial topsoil (20 Technosols overall). The age since construction varied between 2 and 64 years. This indirect measure of the colonization process, along a chronosequence, has been widely used in a post-mining reclamation context (Frouz et al., 2001; Hlava & Kopecký, 2013; Pižl, 2001) and more recently in urban soil context (Carpintero & Reyes-López, 2014; Smetak, Johnson-Maynard, & Lloyd, 2007). Data on age and type of topsoil is detailed in Table S1 in Supporting information. They were obtained by interviews with park managers and gardeners and were digitized in a GIS (Geographic Information System).

2.2. Macrofauna sampling and identification

Ants and earthworms were sampled in five subsamples per site/Technosol, according to an adaptation of the Tropical Soil Biodiversity and Fertility method (TSBF) (Anderson & Ingram, 1994; Lavelle, 1988). First retrieval of organisms at the soil surface was done by applying Formalin (0.4% dilution) twice on a 25 cm × n25 cm area during half an hour. After this step, a block of soil 15 cm deep was then dug up to be hand-sorted for retrieval of ants and earthworms of the subsurface. Ants and adult earthworms were identified to the species level using identification keys [respectively (Seifert, 2007) and (Bouché, 1972; Cuendet, 2001)].

The five subsamples per Technosol were distributed at each corner of a 10 × 10 m^2 plus one in the middle of the square. Overall, 100 samples (20 sites × 5 samples per site) were collected. The sampling took place from 02 April to 10 May 2013, when most earthworms are active (Bouché, 1972).

2.3. Environmental parameters

2.3.1. Local scale

2.3.1.1. Soil physicochemical properties. We sampled soils (organo mineral horizon, between 0 and 15 cm) in each Technosol in order to characterize soil physicochemical properties at each sampling site. One soil sample was taken near each subsample (at 25 ± 5 cm) in order to avoid its contamination by formalin, collected with a 15 cm long − 7 cm diameter auger.

Particle size was measured without previous carbonate removal considering 3 classes of size (Fine <2 μm; Medium >2 μm and <20 μm; Coarse > 200 μm; NFX 31–107 without decarbonatation). Regarding the chemical properties, we measured: soil

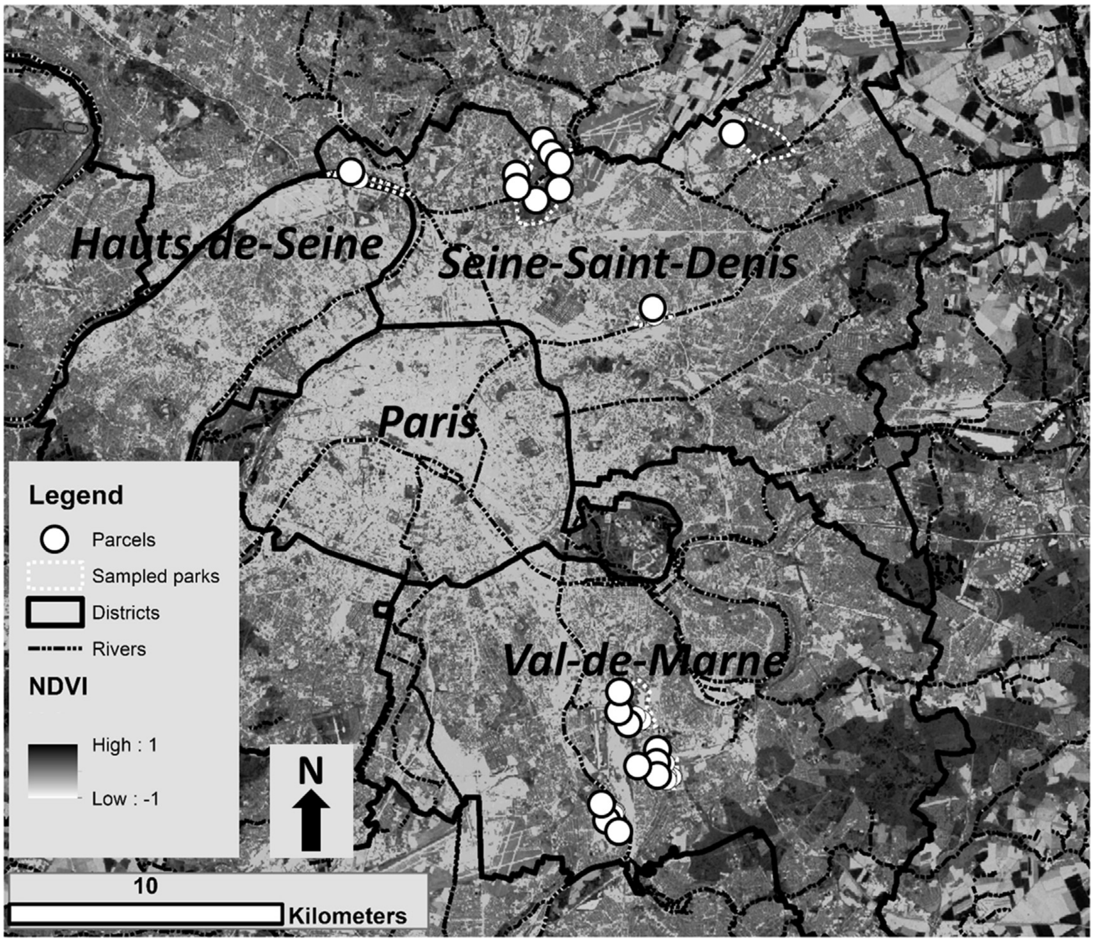

Fig. 1. Map of the location of the Technosols.

organic matter (SOM, $g.kg^{-1}$; Loss on ignition, Duchaufour, 1956), cation exchange capacity (CEC, $cmol^{+}.kg^{-1}$; Metson/NFX 31–130), bioavailable phosphorous (P_2O_5, $g.kg^{-1}$; Olsen/NF ISO 11263), exchangeable potassium (K_2O, $g.kg^{-1}$; Water extraction 1/5 and ICP AES dosage/NF ISO 10 390), pH (Water/NF ISO 11263) and five trace metals commonly found in urban areas (Cd, Cu, Ni, Pb and Zn, $mg.kg^{-1}$;). See Table S2 for detailed protocols.

2.3.1.2. Management practices. Interviews of gardeners and park managers were focused on three lawn management practices that might influence soil properties: frequency of lawn mowing/cutting per year, height of mowing/cutting (3 classes: 0–5, 5–10, 10–15 cm) and mulching (yes or no).

2.3.2. Landscape scale

Normalized Difference Vegetation Index (NDVI) was computed from a Landsat 7 satellite image (2007; 30 m resolution). NDVI is based on the calculation between visible red (VIS) and near-infrared (NIR) bands [$NDVI = (NIR - VIS)/(NIR + VIS)$] and indicates the amount of vegetation (Kerr & Ostrovsky, 2003). To characterize landscape context around each Technosol, we calculated the surrounding vegetation index (SGI) in a 100 m radius from the center plot. SGI is the mean of all NDVI values. The size of the circle was chosen according to the dispersal capabilities of earthworms which are very low (around 10–20 m per year) (Edwards & Bohlen, 1996). All the measurements were done with ArcGIS 10.0 software (ESRI, USA).

2.4. Statistical analyses

2.4.1. Community indices

Density of earthworms was the sum of individuals found in the five subsamples of a given Technosol multiplied by 3.2 (16/5) to obtain a number of individuals per m^2. Ant abundance was estimated by summing the number of occurrences of a given ant species on the five subsamples of each Technosol (varying from 0 to 5). Indeed, it is difficult to measure ant abundance as these organisms are social. They live and move in groups composed of hundreds to thousands of individuals. As a consequence, the number of individuals per sampling unit is either null or highly numerous (Gotelli, Ellison, Dunn, & Sanders, 2011). We also considered the species richness of both taxa which was the number of observed species per Technosol.

2.4.2. Relation between variables and physicochemical properties

To test the link between the presence/absence of topsoil and the physicochemical variables, we used Wilcoxon rank tests. Among physicochemical properties, we focused on SOM by testing the effects of the interaction between age and the presence/absence of initial topsoil with a Generalized Linear Model (GLM).

Most of our variables were correlated and could not be combined in the same model (see Tables S3 and S4). We ran a Principal Component Analysis (PCA) on the local scale variables and extracted the coordinates of Technosols on axes in order to derive composite variables that are uncorrelated.

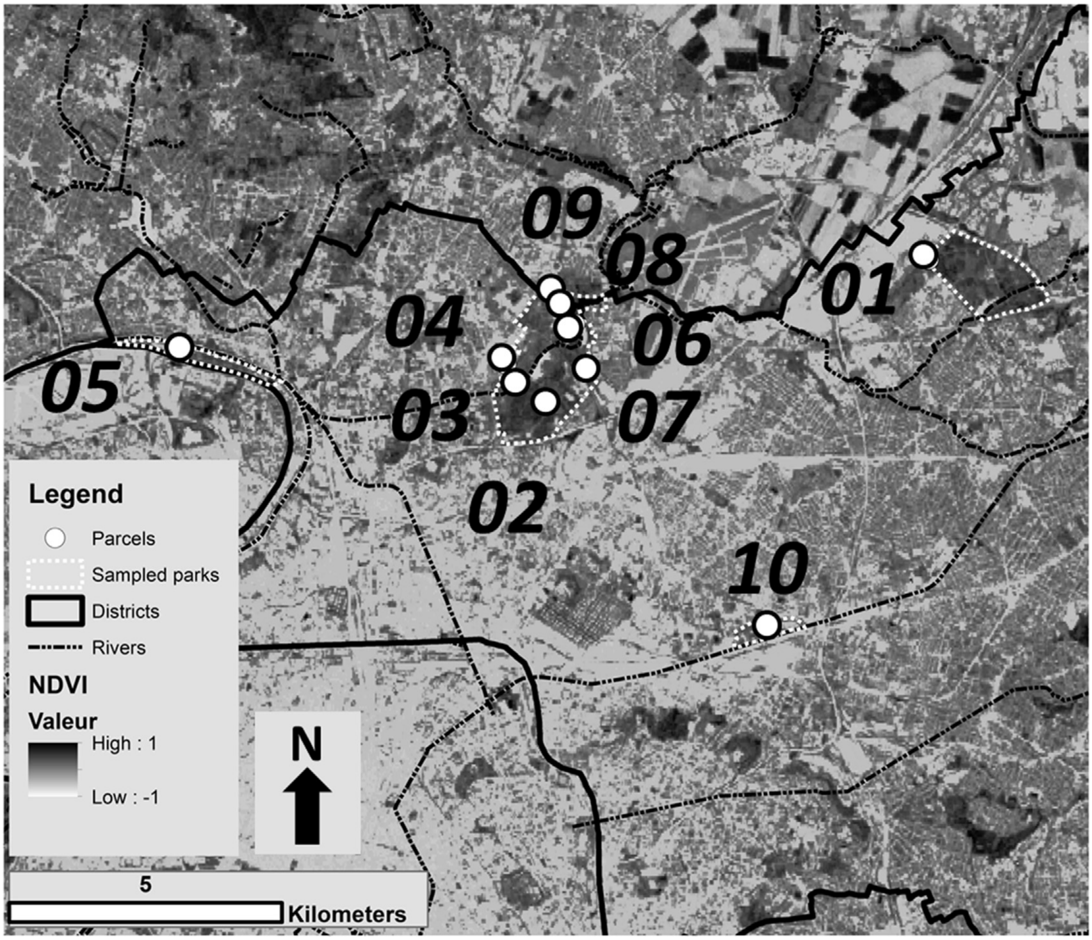

Fig. 2. Map of the Technosols located in Seine-Saint-Denis district.

2.4.3. *Responses of earthworms and ants to environmental parameters*

We constructed GLMs, testing the effects of the two soil factors (topsoil presence/absence and age since the construction), their interaction, the SGI and the coordinates of the Technosols on the two first axes of the PCA. For earthworms, the response variables were density and species richness. For ants, the response variables were abundance and species richness. The GLMs were computed with link log function and a Poisson distribution error, which is well-suited for zero-rich data such as count data (Crawley, 2009). We ran a first model (response variable~ topsoil absence/presence + age + SGI + PCA Axis 1 + PCA Axis 2) to check for spatial autocorrelation in the residuals using a Moran's I correlogram, where measure of residual similarity was plotted as a function of the distance between pair of points. Significance of Moran's I values was evaluated using a permutation test ($n = 1000$). We selected the first distance between each pair of points, which shows a positive and significant Moran's I value ($p < 0.05$). Using this distance, we computed and added an autocovariate in the GLMs to correct for spatial autocorrelation (response variable~ topsoil absence/presence + age + SGI + PCA Axis 1 + PCA Axis 2 + Autocov) (Dormann et al., 2007) with the spdep package (Bivand, 2012). Because the sampling design was unbalanced, we run a type III sum of squares ANOVA. To facilitate the interpretation of the interaction between age and presence/absence of topsoil, we plotted the effects of the models with the Effect package (John et al., 2015). All statistical analyses were performed using R software (version 3.1.0; R Development Core Team, 2014).

Table 1
Soil physicochemical properties of Technosols. Particle size: fine <2 μm, medium >2 μm and <20 μm and coarse >200 μm, soil organic matter (SOM), bioavailable phosphorous (P_2O_5), exchangeable potassium (K_2O), cation exchange capacity (CEC), Copper (Cu), Nickel (Ni), Lead (Pb), Zinc (Zn). Cd was not presented, as values were always lower than the detection threshold (6 mg.kg^{-1}).

Parameters	Min–Max	Mean (SD)
Coarse particle size (%)	9.1–85.0	47.3 (21.7)
Medium particle size (%)	9.3–65.8	33.8 (17.5)
Fine particle size (%)	5.7–28.2	17.6 (5.9)
pH	7.4–8.4	8.1 (0.2)
SOM (g.kg^{-1})	28.6–176.1	83.3 (42.4)
P_2O_5 (g.kg^{-1})	0.01–0.08	0.04 (0.02)
K_2O (g.kg^{-1})	0.01–0.16	0.06 (0.04)
CEC (cmol$^+$.kg^{-1})	57.3–148.5	113.7 (25.6)
Cu (mg.kg^{-1})	11.6–473.8	74.5 (114.7)
Pb (mg.kg^{-1})	29.8–594.2	151.7 (183.1)
Ni (mg.kg^{-1})	14.4–51.6	20.1 (8.8)
Zn (mg.kg^{-1})	39.1–860.1	180.3 (202.3)

3. Results

3.1. *Soil characteristics of technosols and relation between variables*

3.1.1. *Soils physicochemical properties*

Soil characteristics are detailed in Table 1. No effect of the presence/absence of topsoil was observed (Fig. 4) but we noticed a significant increase of SOM along age gradient in Technosols with initial topsoil ($p = 0.002$, Fig. S1). SOM and CEC were not positively

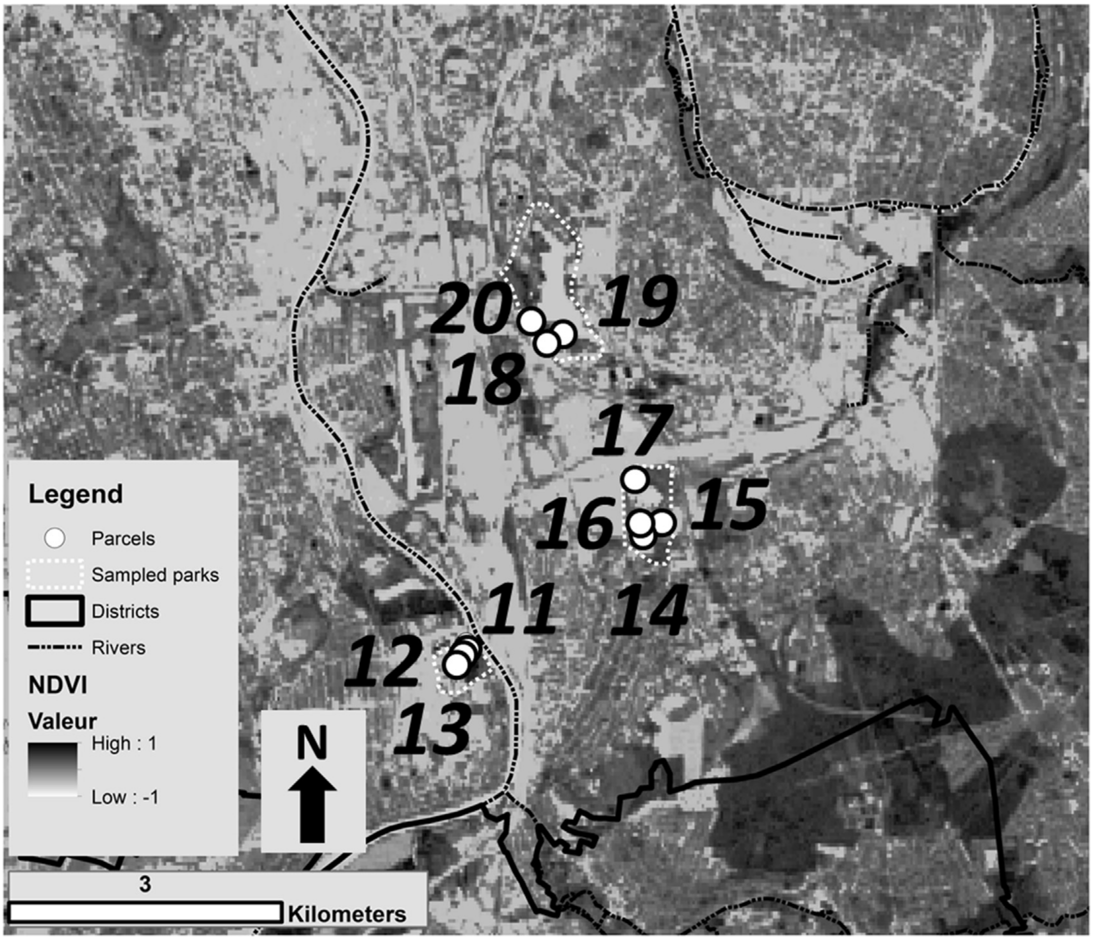

Fig. 3. Map of the Technosols located in Val-de-Marne District.

correlated, probably due to the presence of calcium carbonates which could have a strong impact on CEC.

3.1.2. Reduction of variables

The PCA showed a linear relation among many environmental variables and the two axes explained 48% of variance (Fig. 5). Along axis 1, which extracted 31.3% of the total variance, we observed that the axis was positively associated with an increase of trace metal concentrations (Pb, Cu, Ni and Zn) and coarse particles. Axis 1 is interpreted as an increase gradient of soil contamination and particle size. Axis 2 which captures 16.7% of the variance was more difficult to interpret. It was related to a gradient of increasing P_2O_5 and of decreasing CEC and in a less extent SOM gradient. Overall, practices were poorly related to the two axes. The two ellipses representing the two types of Technosols were almost entirely superposed which means that no major differences have been observed between the absence/presence of topsoil for the variables we studied.

3.2. Response of abundance/density and species richness

3.2.1. Earthworm communities

Overall, we collected 1185 earthworms (392 adult individuals, 33.1%) belonging to 17 species. Richness varied between 1 to 8 and around a mean of 4.6 (SD 2.3). The five most abundant species were *Lumbricus castaneus* (28.1% of the adult abundance, Table S5 for species authority) *Aporrectodea caliginosa* (18.6%), *Lumbricus terrestris* (14.0%), *Allolobophora chlorotica* (12.0%) and *Lumbricus centralis* (9.2%). Densities varied between 0 and 171 individuals.m^{-2} and around a mean of 93.4 (SD 44.6) individuals.m^{-2}.

We observed a significant negative effect of the presence of topsoil on density (Table 2). We also observed that abundance significantly decreased along age gradient (Table 2). When distinguishing the effect of age according to the presence/absence of topsoil, we found that the density of earthworms significantly increased along age gradient in Technosols with initial topsoil whereas it decreased in Technosols without topsoil (Table 2, Fig. 6). We also observed a significant negative effect of the first axis of PCA: a negative effect of Pb, Zn and coarse particles and a positive effect of pH and fine particles.

For species richness, we only observed a significant negative effect of the age (Table 2). The interaction between the presence/absence of initial topsoil and age was close to the significance value ($p = 0.053$, Table 2). Species richness tended to increase in Technosols with initial topsoil along age gradient (Fig. 6).

3.2.2. Ant communities

Overall, we sampled 150 occurrences of ants belonging to 12 species. The number of species in each Technosol ranged from one to six (on average 3.6 ± 1.1). The five more abundant species were *Lasius niger* (32.7%), *Myrmica scabrinodis* (25.3%), *Solenopsis sp* (16.0%), *Lasius flavus* (12.0%) and *Ponera coarctata* (3.3%).

We observed a significant negative effect of the presence of initial topsoil on abundance in Technosols. However, we observed a significant effect of the interaction between the presence/absence of initial topsoil with age (Table 2). Similar to earthworms, abundance of ants increased along age gradient in Technosols with initial

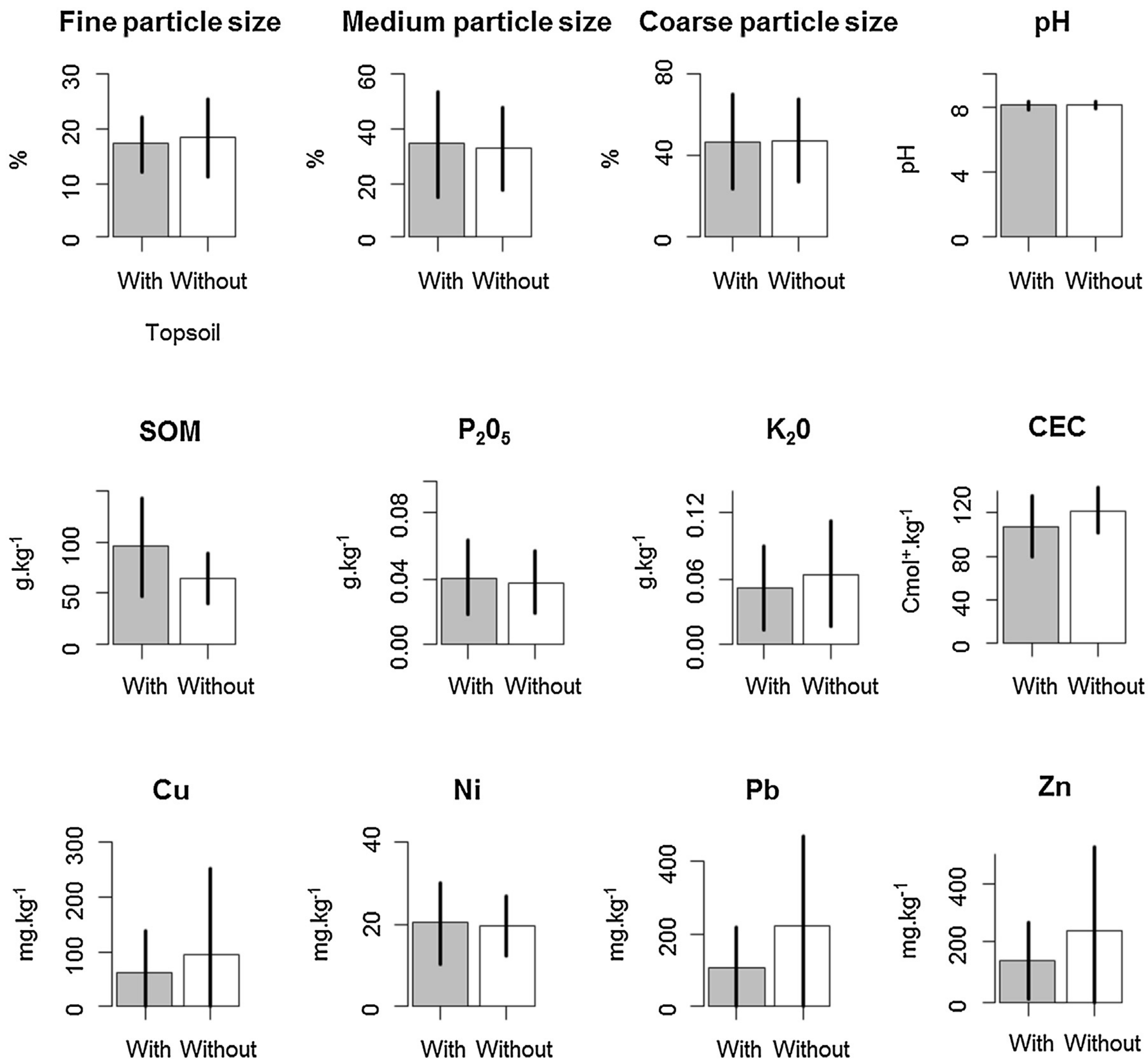

Fig. 4. Soil physicochemical properties among Technosols with or without topsoil.

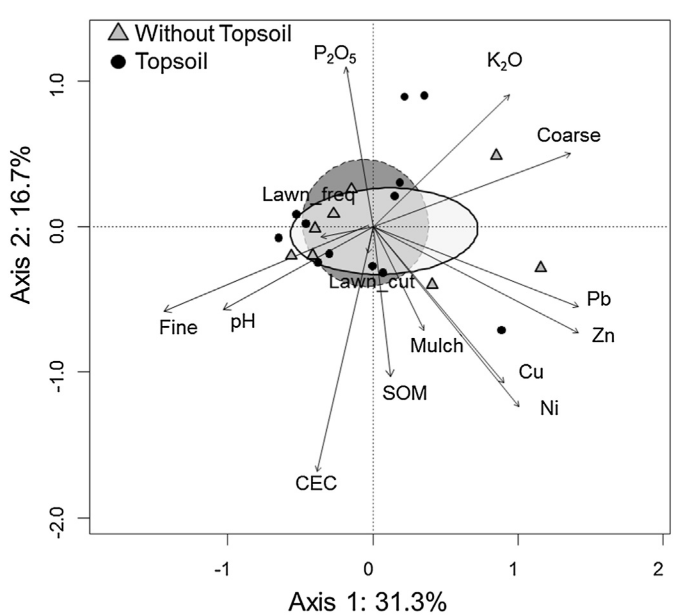

Fig. 5. Principal component analysis using environmental variables (soil physicochemical properties and management practices).

topsoil, but decreased without topsoil (Fig. 6). We noted a negative effect of the SGI on abundances (Table 2).

No significant effect on species richness was observed (Table 2).

4. Discussion

4.1. Soil physicochemical properties of technosols

As with most urban soils, our sampled Technosols were basic with a high pH value, probably due to high concentrations of calcium carbonates. This can be explained by both the calcareous materials of the parent material of Ile-de-France (the region of Paris) (Antoni et al., 2013) and the fact that calcium carbonates are an important component of gravel, cement and concrete (Scharenbroch, Lloyd, & Johnson-Maynard, 2005), which are mixed in most of anthropogenic backfills found in urban soils (Pouyat et al., 2010), or to the leaching of surface runoff waters, previously in contact with concrete buildings (Messenger, 1986).

On average, we found SOM concentrations similar to what Edmondson, Davies, Gaston, & Leake et al. (2014) observed in English urban allotments (on average 80 $g\,kg^{-1}$). but our values were much more heterogeneous. We observed a SD four times greater than in Edmondson et al., (2014).

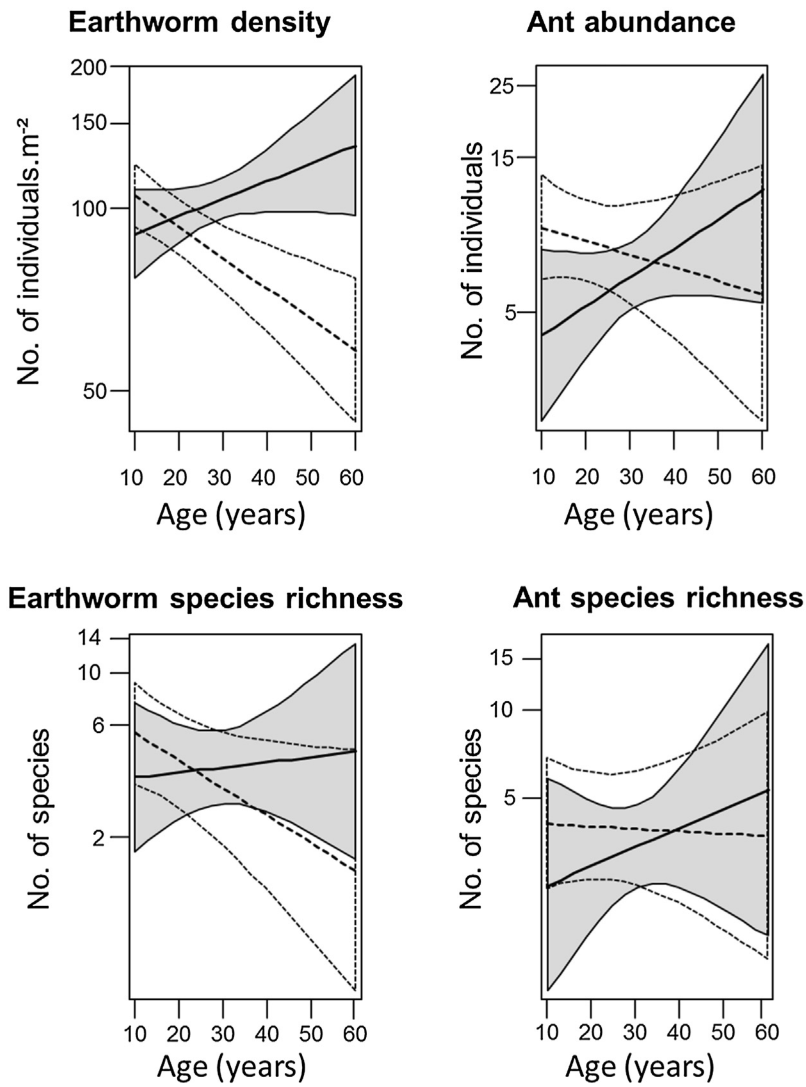

Fig. 6. Plot of the effect of the interaction between absence/presence of topsoil and age on abundance/densities and species richness of earthworm and ant communities.

Similar to other urban soils, we observed a pollution by trace metals (Pouyat et al., 2010). Except for cadmium, concentrations of trace metals were frequently higher than the regional pedo-geochemical background values (Mathieu, Baize, Raoul, & Daniau, 2008) and in some cases even the regulatory guidelines which are based on sewage-slug application limits (Mench & Baize, 2004).

Surprisingly, the soil physicochemical properties of Technosols did not vary with the presence of initial enrichment of topsoil. These properties might also have been affected by the presence of other urban inputs such as atmospheric deposition (Edmondson et al., 2014; Park et al., 2010). A second explanation is that physicochemical properties are affected along the age gradient, depending on the initial presence/absence of topsoil. This is the case for SOM, which increased along the age gradient only in presence of an initial topsoil addition.

4.2. Influence of initial conditions of Technosols on soil organisms

Contrary to our expectations, we did not find an overall increase of abundance/density along an age gradient (H1). In fact, we observed a significant relationship between age and abundance/density only in Technosols with the initial input of topsoil, an example of the importance of Technosols initial conditions for both ants and earthworms (H2). As proposed by the conceptual framework of soil colonization by soil organisms and soil formation (Jenny, 1994), a positive effect of time on abundance/density has been previously documented in post-mining reclamation sites (Hendrychová, Šálek, Tajovský, & Řehoř, 2012; Hlava & Kopecký, 2013) and urban areas (Brown, Miller, Brewster, & Fell, 2013; Buczkowski & Richmond, 2012; Smetak et al., 2007). However, those studies did not strictly investigate the effect of initial conditions which could profoundly change the trajectories of soil formation.

As reviewed by Walker et al. (2010), many authors considered that a given soil community could have various potential trajectories driven by environmental changes induced by initial abiotic conditions. Walker et al. (2010) considered that the initial input of organic matter is one of these important conditions. In our case study, the initial presence of topsoil above backfills during urban park settlement could have increased the initial stock of SOM, which could have been responsible for several processes beneficial to soil formation such as the retention of clays through organo-mineral complex formation, the retention of water and the increase in soil fertility through organic matter mineralization (Stockmann, Minasny, & McBratney, 2011). This in turn could favor the settlement of soil organisms, which could have improved their abiotic environment with positive consequences on their survival through niche construction (Odling-Smee, Laland, & Feldman,

Table 2
Effects of the different variables on abundance/density and species richness from Generalized Linear Models. Estimates with their standard deviation and p values from Anova type III were given. Significance levels were calculated with a type III ANOVA. PCA axis 1 = gradient of soil contamination and particle size, PCA axis 2 = gradient of increasing P_2O_5 and decreasing CEC and SOM, SGI = Surrounding Greening Index, Autocov = autocovariate.

	Technosol factors						Soil parameters and management practices							
	Presence of topsoil		Age		Presence of topsoil x Age		PCA axis 1		PCA axis 2		SGI		Autocov	
	Estimate (SD)	p	Estimate (SD)	p	Estimate (SD)	p	Estimate (SD)	p	Estimate (SD)	p	Estimate (SD)	p	Estimate (SD)	p
Earthworms														
Density	−0.77 (0.14)	0.003	−0.02 (0.01)	<0.001	0.03 (0.01)	<0.001	−0.49 (0.23)	0.04	0.25 (0.23)	0.28	0.74 (0.48)	0.12	0.01 (0.01)	0.04
Species richness	−0.97 (0.70)	0.17	−0.02 (0.01)	0.01	0.04 (0.02)	0.053	0.30 (0.61)	0.61	0.57 (0.60)	0.35	0.99 (1.31)	0.45	0.08 (0.07)	0.26
Ants														
Abundance	−1.44 (0.58)	0.01	−0.01 (0.01)	0.56	0.03 (0.01)	0.02	0.09 (0.52)	0.85	0.52 (0.58)	0.36	−3.02 (1.27)	0.01	−0.02 (0.04)	0.45
Species richness	−0.99 (0.75)	0.18	−0.01 (0.01)	0.95	0.02 (0.02)	0.26	−0.07 (0.67)	0.91	0.50 (0.73)	0.49	−1.11 (1.57)	0.46	−0.02 (0.01)	0.83

2003), leading to a positive feedback loop between biotic and abiotic components.

Finally, recent studies highlighted that soil formation is often faster in Technosols than in more natural soils (Rokia et al., 2014; Scalenghe & Ferraris, 2009). The divergence of soil abiotic properties created by the presence/absence of topsoil could have affected earthworm and ant communities rapidly; in less than 20 years in our study.

4.3. Limited number of species and limited response of species richness

Both earthworm and ant communities were composed of a few generalist species of the regional pool could have limited the response of species richness to the variables tested.

For earthworms, this narrow pool was composed of *L. castaneus*, *L. terrrestris*, *A. caliginosa* or *A. chlorotica*. All these species can be found in many types of habitat but they are more abundant in open habitats (Bouché, 1972). This subset was present in the 8 studies reviewed by Pouyat et al. (2010). We conclude that earthworms could be facing a biotic homogenization (sensu McKinney & Lockwood, 1999) caused by urbanization. Similar to earthworms, the few ant species captured are the most widespread species from the regional pool (Blatrix, Galkowski, Lebas, & Wegnez, 2013). The impoverishment of ants caused by urbanization has been observed in many geographic contexts (Antonova and Penev, 2006; Carpintero & Reyes-López, 2014; Slipinski, Zmihorski, & Czechowski, 2012; Vepsäläinen et al., 2008). As in many northern European cities (reviewed by Vepsäläinen et al., 2008), ant communities of urban parks were mainly composed of the topsoil omnivorous *L. niger* and to a lesser extent by the hypogeic and roots aphids breeding *L. flavus* (Seifert, 2007). These two species are considered as anthropophilic species meaning that they benefit from the association with human activities (Antonov, 2008; Slipinski et al., 2012).

The species richness did not significantly respond to any of our parameters, and none of our hypotheses were supported. The small size of the pool of species may have limited significant variations of species richness between Technosols.

4.4. A contrasting effect of surrounding greening index and management

Surrounding greening index (SGI) only affected ant abundance. Similar to Philpott et al. (2014), we observed a negative effect of the amount of surrounding vegetation in a 100m-radius on ant abundance failing to our last hypothesis (H3). Some ants could have the ability to use impervious surface as habitats more than vegetated patches. This is particularly the case of the most abundant species of our data set, *L. niger*, which is able to live in basements or roofs (Madre, Vergnes, Machon, & Clergeau, 2013) and even in sidewalk cracks (Blatrix et al., 2013). Impervious surfaces may be more useful sources than vegetated surfaces for some ants. More studies are clearly needed on urban ant's ecology. In most species, reproductive females and males have wings and are able to colonize over a distance of many kilometers through mating flights as for *L. niger* or *L. flavus* (Vepsäläinen & Pisarski, 1982). They are less sensitive to landscape barriers such as roads or buildings than no flying species.

The lack of earthworm response to SGI could be explained by two hypotheses. First, the scale selected to measure SGI, a 100-m circle radius, was not adequate for those organisms. Since earthworms can have active dispersal distance ranging from 0.2 to 14 m per year (Caro, Decaëns, & Mathieu, 2013; Eijsackers, 2011; Torres-Leguizamon, Mathieu, Decaëns, & Dupont, 2014). Second, human activities associated with less intensive soil transportation than soil construction such as gardening could have involved passive dispersal. Passive dispersal of eggs or adults is sometimes considered important for long distance dispersal of earthworms (Costa et al., 2013; Eijsackers, 2011; Torres-Leguizamon et al., 2014). Globally, dispersal of earthworms in urban landscapes remains poorly understood.

In our study, the only significant effect of soil and management properties on abundance of earthworms was a negative effect of Axis 1: higher trace metal contamination, coarser particle size. The deleterious effect of trace metals on many species of earthworms is well documented (Edwards & Bohlen, 1996). Management actions such as lawn cutting or mulching were not significant. Few long-term monitoring studies of management practices have been set in the soils of urban parks to better understand slow temporal dynamics.

4.5. Implications for management of soil in urban parks

Globally urban soils are still a neglected resource and are poorly integrated in management policies (Bullock & Gregory, 2009; Lehmann & Stahr, 2007). This issue is crucial one for Technosols, which are by definition made of technogenic materials and should be designed with consideration for soil macrofauna. Our study had the goal of better integrating soil biodiversity and especially soil ecosystem engineers, such as earthworms and ants, into management policies.

First, initial coverage of topsoil over backfills favors the establishment of numerous soil ecosystem engineers over time periods greater than 20 years. The initial stock of organic matter contained by topsoil seems to play a decisive role in long term community building. Current practice, which plants urban park vegetation without topsoil addition, can lead to a decreasing abundance of soil ecosystem engineers along time. To enhance the quality of Technosols without the coverage presence of topsoil backfill with other materials containing more organic matter, such as green waste or sewage sludge composts, available in cities.

Second, in our study it took decades for earthworms and ants to get close to densities found in open habitats (Edwards & Bohlen, 1996) even with coverage of topsoil. This implies that the destruction or the disturbance of the soil is a crucial decision. Gains and losses in soil macrofauna and consequences on ecosystem services have to be carefully evaluated (Jim, 1998), for instance with recent indicators (Vrščaj, Poggio, & Marsan, 2008). The earthworm and ant abundances or species richness should be considered in relation to ecosystem services such as water regulation, carbon storage and primary production (Blouin et al., 2013; Kremen, 2005; Lavelle et al., 2006). With more knowledge about the link between manager practices and macrofauna diversity trajectories, it could become realistic to manage urban parks for greater to support more sustainable and resilient cities.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2016.10.002.

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