Latent extinction risk of soil fauna in Beijing: a 4-year study from 2013 to 2016
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\textbf{ABSTRACT}

Soil ecosystems are far more functionally valuable than previously thought, but soil animals are less visible and often overlooked. Here, we surveyed population sizes of different animal orders in both urban and rural Beijing from 2013 to 2016, to study the impact of increasing urbanization on the ecology of soil fauna. We found 10 orders had less than 1% of soil-animal population in both urban and rural areas. Populations of 6 orders in urban areas were far smaller than those in rural areas. Between 2013 and 2016, both urban and rural areas had experienced a substantial long-term population decrease, and soil animals in Beijing suffered a 52.8% loss of population. Our study indicates 45.5% of orders may be in danger of local extinction, and 27.3% of orders seem highly susceptible to urbanization. Over just four years the soil-animal population in Beijing is shrinking fast thanks largely to increasing urbanization. This raises the worrying prospect of a future soil fauna that may be at risk of local extinction in cities. It is therefore necessary to provide a pragmatic approach to soil-animal diversity conservation. Moreover, the deeper understanding of soil extinction ecology opens up an exciting frontier of opportunities for future research.

\textbf{Introduction}

Extinction ecology explores how species go extinct locally or globally, but more attention is paid to the aboveground world (Monastersky 2014). To date, the reports on extinction ecology of belowground biota are very scarce, and many outcomes are derived from relatively artificial trials (Gonzalez and Chaneton 2002; Hoyle and Gilbert 2004). Special characteristics of soil habitat cause a huge blind spot in the research on local or global extinctions of soil fauna. Soil animals are often neglected in the study of extinction ecology, partly because the belowground world is often inconspicuous (Li et al. 2020). Indeed, over the course of geological time, belowground organisms including soil fauna are very likely to go extinct (Gaucher, Govindarajan, and Ganesh 2008; Xie et al. 2005).

Studies on soil habitat are often technically challenging, it is an intricately structured 3D habitat. Soil habitats are more layering than nearly any aboveground habitats in the world, including the most extensively vertically layered tropical forests, considering the small size of the soil animals (Peguero et al. 2019; Doblas-Miranda, Sánchez-Piñero, and González-Megías 2009). Due to the high complexity of soil habitats, soil animals could be less impacted by ecological changes than aboveground fauna (TschamkTE et al. 2012). Soils can be insulated against various climate changes such as drought, warming, and extreme events. However, soil habitats are particularly susceptible to anthropogenic stressors like urbanization. Accordingly, from the viewpoint of belowground extinction susceptibility, soil ecologists should pay more attention to anthropogenic stressors than climate changes due to the unique features of soil habitats.

Extinctions do not occur instantaneously, thereby increasing the difficulties of belowground extinction risk assessment. Despite ecologists realizing the negative effects of agriculture, erosion and desertification, humanity still understates the disastrous consequences of soil habitat destruction. Particularly, the urbanization trend will mainly impact the soil habitats for years to come. Urbanization could post a major challenge to soil fauna via soil tillage, fertilization, and irrigation, resulting in the habitat loss for a subset of the community (Lennon et al. 2012). These drivers could not only trigger a deterioration of soil structure by destroying soil aggregates, but could also cause the competitive exclusion of soil animals and subsequently an oligotrophic life-strategy (Rillig and Mummey 2006). In terms of metropolises, restoring soil habitats can help forestall impending local extinctions, so it is necessary to preserve some suitably interconnected soil habitats at a certain spatial scale. Here, we surveyed the soil fauna dynamics in the Chinese capital, Beijing, with 21.5 million people, between 2013 and 2016. By studying the biodiversity
shift, we analyzed the effects of urbanization on local soil communities, and then assessed the belowground extinction risk. In this study, we addressed three main questions: 1) the soil animal species diversity in urban and rural areas, and the population sizes of various animal orders, 2) the differences in population sizes of various orders between urban and rural areas, 3) the annual population dynamics of various orders from 2013 to 2016. When extrapolating or applying concepts of extinction dynamics to soil fauna, we should remain extremely cautious, as we enter exciting but unchartered territory.

Materials and methods

Sample collection and identification

It is well known that the areas within the Fifth Ring Road are defined as urban Beijing, whereas the outside areas are defined as rural Beijing. The experiments were established in April 2013, April 2014, April 2015 and April 2016, respectively, throughout Beijing. We chose 6 representative areas (3 in urban areas and 3 in rural areas) as we expected there to be a relatively large species pool from which colonization could occur. We set out 4 traps in each area as four replicates. Hence, overall 23 holes (a hole was destroyed during the experiment; Supplementary Fig. 1), each measuring 16 × 16 cm and 80 cm deep, were dug across Beijing. In each of the holes we created a “trap space” measuring 15 × 15 cm and 70 cm deep using a polyvinyl chloride (PVC) pipe. The PVC pipe was rigid enough to prevent soil from entering the trap space, while soil animals could enter through the 32 small holes (2 × 2 cm) in the pipe. Then, we put the trap containing 600 ml supersaturated salt solution into the space (Supersaturated salt solution is colorless and odorless, its function is just to prevent trapped soil animals from escaping), and then covered with the PVC lid and the soil (Supplementary Fig. 2). Approximately 100 g litter was placed on top of each replicate to maximize potential colonization. The litter, consisting mainly of leaves and twigs, was collected at the site and homogenized.

We sampled the experiment a year after establishment, in May 2014, May 2015, May 2016 and May 2017, respectively. From all replicates of six areas, we collected one composite sample from each trap in the organic horizon below the litter layer. The samples were placed in plastic tubes and stored at 4°C until processed. Extraction of soil animals commenced the day after the samples were collected. The collected samples were identified using the digital microscopy (VHX-1000, Keyence, Osaka, Japan) based on morphological characteristics. All individuals were identified to order level due to difficulties with reliable identification at species level. All individuals of different orders were counted, and the population size was estimated by sorting through the samples and determining all morphotypes. The soil-animal orders were considered to be at risk of local extinction when their proportion of population size was less than 1%, while the superior orders were identified when the population proportion remain above 10%.

Data analysis

Descriptive statistics were given as the mean values and standard errors of the mean. Differences in the population sizes of various orders between urban and rural areas were examined using Student’s t-test. Annual population dynamics of various orders from 2013 to 2016 were analyzed using one-way analysis of variance (ANOVA) with the Tukey’s HSD test of significance at the 5% level of statistical significance. In all tests, P values <0.05 were considered significant. All statistical analyses were conducted using the SPSS 20.0 software (IBM, Armonk, NY).

Results

Belowground diversity in urban and rural areas

Between 2013 and 2016, soil animals across 22 orders were collected in Beijing. Among them, 19 orders were found in urban areas, while 20 orders were trapped in rural areas (Table 1). From a population size perspective, the four orders including Hymenoptera (27.26 ± 4.15%), Hemiptera (18.27 ± 3.68%), Acaridea (16.53 ± 2.88%) and Collembola (11.3 ± 2.78%) were superior to other orders in urban areas, their population proportion all remained above 10%. Whereas the seven orders including Symphyla (0.72 ± 0.18%), Geophilomorpha (0.68 ± 0.21%), Scolopendromorpha (0.36 ± 0.23%), Orthoptera (0.13 ± 0.08%), Corrodentia (0.11 ± 0.1%), Pseudoscorpionida (0.03 ± 0.03%) and Neuroptera (0.02 ± 0.02%) were likely to be in danger of local extinction, their proportion of population size was less than 1% (Figure 1(a)). In the rural areas, the three orders including Collembola (32.73 ± 3.79%), Acaridea (17.42 ± 2.94%) and Coleoptera (11.62 ± 1.43%) were dominant (population proportion >10%). However, the eight orders including Diplura (0.77 ± 0.33%), Lepidoptera (0.57 ± 0.37%), Corrodentia (0.25 ± 0.23%), Scolopendromorpha (0.22 ± 0.14%), Thysanoptera (0.07 ± 0.04%), Symphyla (0.06 ± 0.03%), Siphonaptera (0.03 ± 0.03%) and Haplotaxida (0.03 ± 0.03%) might be becoming endangered in the area far beyond Beijing city (population proportion <1%) (Figure 1(b)). Overall, nine orders (40.9% of 22 collected orders) including Lepidoptera, Corrodentia, Scolopendromorpha, Thysanoptera, Symphyla, Siphonaptera, Haplotaxida, Orthoptera and Neuroptera had less than 1% of soil animal population
Table 1. Number and proportion of collected soil animals across 22 orders in urban and rural Beijing (Mean ± SE).

| Animal order      | Urban          | Proportion | Rural          | Proportion |
|-------------------|----------------|------------|----------------|------------|
| Hymenoptera       | 64.8 ± 23.33   | 7.04 ± 2.42% | 26.73 ± 16.2   | 7.04 ± 2.42% |
| Coleoptera        | 2.51 ± 0.75    | 0.02 ± 0.02% | 10.52 ± 1.22   | 0.02 ± 0.02% |
| Diptera           | 1.73 ± 0.51    | 0.001       | 0.001          | 0.001       |
| Hemiptera         | 43.07 ± 14.45  | 1.53 ± 0.86% | 3.59 ± 2.86    | 1.53 ± 0.86% |
| Orthoptera        | 0.22 ± 0.15    | 0.001       | 0.001          | 0.001       |
| Thysanoptera      | 0.07 ± 0.05    | 0.02 ± 0.02% | 0.07 ± 0.05    | 0.02 ± 0.02% |
| Lepidoptera       | 0.02 ± 0.02    | 0.001       | 0.001          | 0.001       |
| Neuroptera        | 1.23 ± 2.64    | 32.73 ± 3.79% | 50.68 ± 11.04  | 32.73 ± 3.79% |
| Diplura           | 7.07 ± 1.63    | 0.02 ± 0.02% | 0.02 ± 0.02%   | 0.02 ± 0.02% |
| Symphyta          | 4.38 ± 1.20    | 0.02 ± 0.02% | 0.02 ± 0.02%   | 0.02 ± 0.02% |
| Polydesmida       | 0.96 ± 0.21    | 0.02 ± 0.02% | 0.02 ± 0.02%   | 0.02 ± 0.02% |
| Lithobiomorpha    | 4.38 ± 1.20    | 0.02 ± 0.02% | 0.02 ± 0.02%   | 0.02 ± 0.02% |
| Geophilomorpha    | 0.84 ± 0.39    | 0.02 ± 0.02% | 0.02 ± 0.02%   | 0.02 ± 0.02% |
| Scoleopendromorpha| 0.33 ± 0.21    | 0.02 ± 0.02% | 0.02 ± 0.02%   | 0.02 ± 0.02% |
| Acaridae          | 1.44 ± 2.44    | 0.02 ± 0.02% | 0.02 ± 0.02%   | 0.02 ± 0.02% |
| Araneida          | 1.51 ± 0.33    | 0.02 ± 0.02% | 0.02 ± 0.02%   | 0.02 ± 0.02% |
| Pseudoscorpionida | 0.04 ± 0.03    | 0.02 ± 0.02% | 0.02 ± 0.02%   | 0.02 ± 0.02% |
| Haplotaxida       | 0.02 ± 0.02    | 0.02 ± 0.02% | 0.02 ± 0.02%   | 0.02 ± 0.02% |

Figure 1. Proportions of population sizes across various soil-animal orders in (a) urban and (b) rural areas.

in both urban and rural areas (Supplementary Table 1), concern needed to be raised about these animal orders that were at particular risk of local extinction.

Differences in population sizes between urban and rural areas

Examining the collected number of various animal orders showed that only three orders including Hemiptera ($t_{47.432} = 2.68, P = 0.01$), Diplura ($t_{46.93} = 3.845, P < 0.0001$) and Symphyta ($t_{58.434} = 3.536, P = 0.001$) had significantly larger populations in urban areas than those in rural areas. By contrast, we found the populations of six orders including Coleoptera ($t_{71.546} = -5.607, P < 0.0001$), Diptera ($t_{45.918} = -2.948, P = 0.005$), Lepidoptera ($t_{43} = -2.085, P = 0.043$), Collembola ($t_{47.897} = -3.382, P = 0.001$), Lithobiomorpha ($t_{48.977} = -2.878, P = 0.005$) and Pseudoscorpionida ($t_{43.758} = -3.285, P = 0.002$) in urban areas were far smaller than those in rural areas (Figure 2 and Table 2). Since the level of urbanization in urban Beijing is far higher than that in rural Beijing, soil animals from these six orders were the most susceptible to urbanization. In total, the number of soil animals collected in urban Beijing ($163.6 ± 28.3$) was lower than that in rural Beijing ($176.7 ± 38.3$) ($t_{51} = -0.276, P = 0.783$).

Annual population dynamics from 2013 to 2016

Thanks largely to the urbanization of 2013–2016, population decline was actually accelerating in most of soil animal orders. Both urban and rural Beijing had experienced a substantial long-term population...
decrease (Supplementary Figs 3 and 4, Tables 3 and 4). Between 2013 and 2016, the population size in urban areas sharply decreased by 46.9% to the soil animals across the 19 collected orders (Figure 3(a) and Table 5). Belowground communities in rural areas were generally thought to be less affected by urbanization, but that was not the case in Beijing. Similar to urban areas, the population in rural areas has greatly decreased by 61.2% in just over 4 years, possibly because of the rapid urbanization in rural Beijing (Figure 3(b) and Table 5). Overall, the soil animal populations in both urban and rural Beijing were shrinking fast, and soil animals in Beijing suffered a 52.8% loss of population within 4 years (Figure 3(c) and Table 5).

**Discussion**

**Urbanization, a major extinction risk factor for soil animals**

In extinction ecology, the internationally recognized drivers are habitat loss and fragmentation. Habitat
Table 3. Population dynamics of soil animals in urban Beijing from 2013 to 2016 (Mean ± SE).

| Animal order         | 2013          | 2014          | 2015          | 2016          |
|----------------------|---------------|---------------|---------------|---------------|
| Hymenoptera          | 129.36 ± 88.66| 58.36 ± 18.63 | 6.09 ± 2.18   | 65.33 ± 26.07|
| Coleoptera           | 3.91 ± 2.95   | 1.91 ± 0.65   | 2.65 ± 0.54   | 1.50 ± 0.50   |
| Diptera              | 3.73 ± 1.80   | 1.27 ± 0.47   | 1.55 ± 0.73   | 0.50 ± 0.29   |
| Hemiptera            | 67.09 ± 50.03 | 36.73 ± 24.35 | 40.27 ± 15.45 | 29.42 ± 16.88|
| Orthoptera           | 0             | 0.55 ± 0.55   | 0.36 ± 0.24   | 0             |
| Neuroptera           | 0.27 ± 0.19   | 0             | 0             | 0             |
| Neuroptera           | 0.09 ± 0.09   | 0             | 0             | 0             |
| Collomella           | 18.18 ± 7.91  | 20.27 ± 5.29  | 10.36 ± 3.3   | 1.42 ± 0.68   |
| Diplura              | 2.00 ± 1.00   | 6.55 ± 3.91   | 11.36 ± 4.3   | 8.25 ± 2.63   |
| Symphyla             | 0.73 ± 0.43   | 0.55 ± 0.21   | 1.64 ± 0.41   | 0.92 ± 0.51   |
| Isopoda              | 2.73 ± 1.48   | 5.82 ± 2.95   | 6.09 ± 3.11   | 3.00 ± 1.90   |
| Polydesmida/Julida   | 10.09 ± 7.82  | 7.73 ± 3.27   | 7.27 ± 3.95   | 1.58 ± 0.63   |
| Lithobiomorpha       | 1.00 ± 0.71   | 3.18 ± 1.29   | 5.18 ± 2.37   | 1.58 ± 0.82   |
| Geophilomorpha       | 0.64 ± 0.24   | 1.91 ± 1.53   | 0.82 ± 0.3    | 0.08 ± 0.08   |
| Scoleopendromorpha   | 0             | 0             | 1.00 ± 0.82   | 0.33 ± 0.26   |
| Acaridae             | 16.73 ± 7.54  | 12.64 ± 3.06  | 7.36 ± 0.94   | 20.58 ± 5.03  |
| Araneida             | 0.36 ± 0.15   | 1.09 ± 0.64   | 2.73 ± 0.86   | 1.83 ± 0.63   |
| Pseudoscorpionida    | 0             | 0             | 0             | 0.17 ± 0.11   |
| Haplotaxida          | 0             | 0.09 ± 0.09   | 0             | 0             |

Table 4. Population dynamics of soil animals in rural Beijing from 2013 to 2016 (Mean ± SE).

| Animal order         | 2013          | 2014          | 2015          | 2016          |
|----------------------|---------------|---------------|---------------|---------------|
| Hymenoptera          | 86.18 ± 63.06 | 16.73 ± 7.22  | 1.18 ± 0.54   | 2.82 ± 1.1    |
| Coleoptera           | 11 ± 2.76     | 12.27 ± 3.25  | 12.18 ± 2.13  | 6.64 ± 0.83   |
| Diptera              | 12.18 ± 8.01  | 11.82 ± 5.36  | 11.27 ± 5.81  | 4.91 ± 1.43   |
| Hemiptera            | 0.82 ± 0.63   | 0.09 ± 0.09   | 12.73 ± 11.35 | 0.73 ± 0.3    |
| Thysanoptera         | 0.18 ± 0.18   | 0.27 ± 0.19   | 0.07 ± 0.09   | 0.09 ± 0.09   |
| Siphonaptera         | 0.09 ± 0.09   | 0             | 0             | 0             |
| Corrodenzia          | 0.27 ± 0.19   | 0             | 0             | 0             |
| Lepidoptera          | 0.05 ± 0.39   | 0             | 0.55 ± 0.45   | ± 0.82       |
| Collomella           | 43.27 ± 21.72 | 62.09 ± 20.62 | 81.27 ± 30.42 | 16.09 ± 6.4   |
| Diplura              | 1.09 ± 0.09   | 0.27 ± 0.19   | 0.64 ± 0.47   | 0.82 ± 0.64   |
| Symphyla             | 0.09 ± 0.09   | 0             | 0.55 ± 0.31   | 0             |
| Isopoda              | 4.82 ± 3.46   | 21.45 ± 20.37 | 6.64 ± 3.07   | 0.82 ± 0.58   |
| Polydesmida/Julida   | 36.73 ± 28.37 | 77.45 ± 70.56 | 0.64 ± 0.31   | 0.36 ± 0.28   |
| Lithobiomorpha       | 3.64 ± 1.08   | 7.91 ± 2.94   | 9.36 ± 3.52   | 6.82 ± 1.94   |
| Geophilomorpha       | 1.45 ± 0.37   | 1.09 ± 0.37   | 2.45 ± 0.76   | 0.55 ± 0.37   |
| Scoleopendromorpha   | 0             | 0             | 0.55 ± 0.31   | 0             |
| Acaridae             | 8.82 ± 2.87   | 41.55 ± 21.65 | 12.73 ± 5.84  | 37.45 ± 16.99 |
| Araneida             | 0.73 ± 0.63   | 1.64 ± 0.79   | 2.64 ± 1.38   | 1.27 ± 0.76   |
| Pseudoscorpionida    | 0.09 ± 0.09   | 1.09 ± 0.46   | 2 ± 1.14      | 1.36 ± 0.43   |
| Haplotaxida          | 0             | 0.09 ± 0.09   | 0             | 0             |

Figure 3. Population dynamics of soil animals from 2013 to 2016. (a) Total population size in urban areas, (b) Total population size in rural areas, (c) Total population size in Beijing.

Loss is often attributed to the very rapid disappearance of the autotrophs dominating an area. Indeed, in some cases, the key trigger of habitat loss is urbanization from a perspective of belowground organisms. We found the soil animals across 6 orders (27.2% of collected orders) had a considerably smaller population in urban areas than that in rural areas. The rate of urbanization in urban Beijing (83.6%) is far higher than that in rural Beijing (48.5%) (Wang et al. 2018), so the population of soil animals in urban areas is shrinking
fast. For belowground ecosystem, urbanization can lead to the eradication of autotrophs and fragmentation of the soil surface via cementing, meeting the common definitions of habitat loss adopted in the aboveground ecology. In fact, the abundance not only of soil animals but also of other belowground organisms such as predatory nematodes declines due to urbanization (Pavao-Zuckerman and Coleman 2007).

From an urbanization viewpoint, a series of anthropogenic activities pose a long-term threat to soil animals that could even cause local extinctions. In terms of colonial expansion and land exploitation, soil tillage and fertilization are really a pretty typical example. Soil tillage could trigger a deterioration of soil structure by destroying soil aggregates, while fertilization may lead to the competitive exclusion of soil animals and subsequently an oligotrophic life-strategy (Rillig and Mummey 2006). Both of the drivers could post a major challenge to soil fauna, and thus they are some of the reasons for the habitat loss for a subset of the community (Lennon et al. 2012). Besides, irrigation acting as another driver has been associated to local extinctions of earthworm taxa (Manono 2014), which explains the very small population of earthworm in Beijing. However, earthworm was not alone in facing the risk of local extinctions. More seriously, we found 40.9% (9/22) of soil animal orders had less than 1% of population in both urban and rural Beijing. Thus belowground diversity may be extremely challenged, it appears nearly half of soil animal orders are in danger of local extinction due to anthropogenic activities with urbanization. Beijing has the world’s biggest subway system, its total subway mileage (699.3 km) is No.1 in the world. There is no denying that the China economic miracle of the last two decades has put emphasis on economic development and urbanization, but the intensification of land use is also very likely to severely affect soil ecology. A number of bacterial (Fierer et al. 2013) and fungal (Verbruggen et al. 2014; Liu and Zhang 2020) taxa have proven to be highly susceptible to intensification of land use, so increasing amounts of evidence show that anthropogenic activities with urbanization can lead to belowground habitat loss and thus soil biodiversity losses. The lack of standardization makes it hard to summarize and measure the extent to which each of these drivers can result in the soil biodiversity losses but belowground ecologists need to work on this, considering that many of these endangered soil animals are absolutely vital to the stability of both below- and above-ground communities (Johnson 2010).

Other potential extinction risk factors for soil animals

Besides urbanization, climate change can also, to some extent, cause habitat loss. Extreme events such as warming and drought have proven to be a challenge for belowground habitats (Meehan et al. 2020; Sheik et al. 2011). Global warming is closely related to air pollution, the average concentrations of PM$_{2.5}$ in Beijing from 2013 to 2016 all exceed the standards of moderate pollution (Gao et al. 2017), possibly creating a continued decline in the population of soil animals in both urban (46.9% loss) and rural (61.2% loss) Beijing. Air pollution can have indirect, substantially more intricate and less intuitive effects on soil properties, greatly affecting belowground ecology. To illustrate, elevated atmospheric CO$_2$ indirectly causes reduced soil aggregate and pore sizes, potentially resulting in an extinction of belowground organisms like large-diameter nematodes (Niklaus et al. 2003). Obviously, there is no pore space given to soil organisms for movement. Moreover, three of Beijing’s annual precipitation from 2013 to 2016 remain below its historical average of 626 mm. Reduced soil aggregation levels follow exposure to drought-affected environments, leading to corresponding decreases in soil pore diameters and possibly to the local extinction of soil fauna. Accordingly, both warming and drought were likely to play a part in the sharp drop (52.8%) in the population of soil animals within 4 years.

Microbial invasions may be another threat to soil animals. Despite comparatively limited attention paid to microbes in the invasion literature, the increasing worldwide human travel causes a greater likelihood of unintentional invasions (Klimek et al. 2020; Dana, Jeschke, and García-de-Lomas 2014; Wilson et al. 2009). Annual visitor arrivals in Beijing can reach up to 320 million, which is extremely likely to cause unintentional invasions in this metropolis. Compared to aboveground macroorganisms, invasions of soil microbes are hard to control and even harder to predict because of their small size. Despite the difficulty of assessing invasion resistance for soil communities, it is obvious that microbial invasion resistance can determine belowground diversity, and the soil taxa

| Year | Population Size | Relative to 2013 | Population Size | Relative to 2013 | Population Size | Relative to 2013 |
|------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 2013 | 256.9 ± 96.9    | −38.3%          | 212 ± 90.2      | 20.5%           | 234.5 ± 64.8    | −11.7%          |
| 2014 | 158.6 ± 43.4    | −59.2%          | 255.5 ± 117.7   | −25.9%          | 207.1 ± 62.1    | −44.1%          |
| 2015 | 104.9 ± 20.9    | −46.9%          | 157.1 ± 37.8    | −61.2%          | 131 ± 21.9      | −52.8%          |
| 2016 | 136.5 ± 34.4    |                | 82.3 ± 15.4     |                | 110.6 ± 19.8    |                |

Table 5. Overall population change of soil animals from 2013 to 2016.
adapting to specific low-diversity habitats actually seem more susceptible to extinction than other taxa (van Elsas et al. 2012). As such, the 9 animal orders considered to be at risk of local extinction in our study may possess adaptations to specific low-diversity habitats, so the stability of their communities in a big metropolis deserves attention.

A final hypothetical risk factor for soil animals could be specialization. Although many soil animals are omnivores with little apparent specialization, some of them display feeding specialization (Bardgett 2005). A long-held view from extinction ecologists is that specialist species may tend more to extinction than generalists as their persistence overly relies on the persistence of their prey (Colwell, Dunn, and Harris 2012). Accordingly, soil animals appear to be more at risk of extinction than other soil organisms, which can significantly affect soil ecosystems considering that litter decomposition largely depends on soil animal activity (Srivastava et al. 2009). It is therefore necessary for belowground extinction ecologists to consider a pragmatic approach to soil animal diversity conservation.

**A pragmatic approach to soil animal diversity conservation**

As a matter of fact, the approach to soil animal conservation is more pragmatic than that for macroscopic aboveground organisms. Soil obviously has enormous benefits for humanity, the loss of soil animal diversity can cause the presence of soil-based opportunistic human pathogens (Berg, Eberl, and Hartmann 2005), which decreases the resistance of clinical microbes and the resilience of belowground ecosystems (Baltz 2008; Ling et al. 2015; Chapin et al. 2000). Soil animal diversity conservation could provide a further reason to monitor progress closely, and thus the great diversity of soil animals begins to be recognized (Martiny et al. 2006; Tiedje et al. 1999).

Belowground ecology shows remarkable improvement over the past several years with the constant development of techniques and bioinformatic analysis pipelines (Prosser 2012; Yang et al. 2013). Belowground extinction ecologists gradually realize that extensive analyses of soil animal taxa are essential to the dynamic analysis of rare taxa, contributing to conservation prioritization (Meiser, Bálint, and Schmitt 2014).

The decline in soil animal diversity seems inevitable, identifying particularly valuable taxa needs to be a high priority in the risk management strategy, as with the earthworm example in our analysis. It is necessary to give priority to conserving soil animal taxa with high ecological value before fully understanding the belowground communities. The keystone soil animal taxa can eventually be found out on the basis of the properties of their respective interaction networks (Dunne and Williams 2009), so soil ecologists should focus on conserving the soil animal taxa that most benefit phylogenetic diversity (Faith 2015). In addition, conserving the fragile soil habitats (where multiple keystone taxa are in danger) via the preservation of soil structure and the maintenance of succession patterns is also a viable conservation strategy (Navarro-García, Casermeiro, and Schimel 2012; Prach and Walker 2011). Since we found 40.9% of collected animal orders were at risk of local extinction in both urban and rural Beijing, many regions in Beijing could be identified as fragile soil habitats thanks to the combination of anthropogenic activities with urbanization and climate change. The “macrobial bias” is the next problem once fragile soil habitats are identified. From a macrobial conservation perspective, protecting ecosystems is generally considered to be meaningless and thus broadly ignored (Griffith 2012). This bias is largely because of the limited broader appeal of soil animals, so the conservation initiatives for soil animal diversity should be well-planned and articulated in sufficiently compelling and accessible ways.

On the other hand, no species lives on earth forever. Extinctions are virtually inevitable in nature, over a long period they provide a chance for surviving organisms and cause speciation rates to rise, which is well-recognized (Yoder et al. 2010). Due to the rapid evolution of soil animals, they should be well-equipped to tackle the novel challenges in the ever-changing world. As a matter of fact, extinctions of soil animals may be far more common than for visible macroscopic ones. Therefore, belowground extinction ecologists need to not only find a pragmatic approach to soil animal diversity conservation but respect the fact that the process of extinction is an inevitable part of the forge of life itself.

**Conclusions**

The impact of urbanization on population sizes of soil fauna was studied from 2013 to 2016. This study found that 9 orders had less than 1% of soil animal population in both urban and rural areas. The populations of 6 orders in urban areas were far smaller than those in rural areas. Both urban (46.9%) and rural (61.2%) areas had experienced a substantial long-term population decrease between 2013 and 2016, and soil animals in Beijing suffered a 52.8% loss of population. This study indicates 40.9% of orders may be in danger of local extinction, and 27.3% of orders seem highly susceptible to urbanization, suggesting that anthropogenic activities with urbanization can lead to belowground habitat loss and soil animal diversity loss. This raises the worrying prospect of a future soil fauna that may be at risk of local extinction in cities. It is therefore necessary to provide a pragmatic approach to soil
animal diversity conservation, and the conservation initiatives for soil animal diversity should be well-planned and articulated in sufficiently compelling and accessible ways.

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Disclosure statement

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