A geostatistical approach to the study of earthworm distribution in grassland

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Abstract

This study characterises the spatial variability of the earthworm species in a conventional grassland system in Le Rheu (Brittany, France) using a geostatistical approach. The first experiment was carried out in autumn 1995 using a systematic grid sampling pattern. Preliminary results describe the spatial variability of Lumbricus terrestris and Aporrectodea caliginosa in relation to soil hydromorphy, at the field scale. The distributions of L. terrestris adults and A. caliginosa adults were correlated positively (Pearson correlation coefficient $\hat{r}=0.56$). These distributions were also correlated with soil hydromorphy: a high-biomass patch corresponded to a well drained area and a low-biomass patch corresponded to a highly hydromorphic area. The distribution of L. terrestris juveniles was very different from the adult distribution and was not correlated to soil hydromorphy.

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1. Introduction

Ecologically, soil is an interactive system consisting of different components: soil physical and chemical characteristics, organic matter, biological activities and soil water characteristics (Coleman et al., 1992). In this interactive system, earthworms can be considered as indicators of the nature and use of the soil: population distribution and dynamics in relation to soil properties, and as regulators of soil structuring processes: interaction between organic matter, soil structure and earthworm communities. Lavelle (1987) defined soil as a hierarchical system owing to the spatial heterogeneity of the bio-physico-chemical soil characteristics. This heterogeneity can be defined at different scales. Extrapolation of processes described at a fine scale (e.g. thin sections, laboratory studies), is possible through a knowledge of the in situ spatial heterogeneity of earthworm community distribution.

The aims of the study were:

– to characterise the spatial variability of earthworm communities in a conventional grassland system at two scales (m² and field plot).
– to establish relationships between the spatial distributions of earthworm species and soil char-
acteristics: at the 1 m² scale, the presence of cattle dung or soil compaction due to cattle or agricultural practices can be important while at the field scale, spatial earthworm distributions could be dependent on soil properties.

2. Materials and methods

2.1. Study area and species sampled

This experiment was carried out in autumn 1995 in a conventional grassland field at Le Rheu (Brittany, France). A systematic sampling of 100 sampling units was carried out in a 54×54 m² field plot. Sample units were 6 m away from each other. The unit size was 1 m², subdivided into 64 equal subunits. Earthworms were collected in each subunit, using the formalin extraction technique (Bouche and Aliaga, 1986) followed by hand-sorting of the soil to a depth of 20 cm in the four central subunits (25×25 cm²). Earthworms collected with the two techniques were preserved in formalin (4% formaldehyde). Earthworms were identified following Bouche (1972) and weighed (formalin weight) in the laboratory. The data base contains coordinates of sample units and abundance and biomass values for earthworm species at two developmental stages (adult and juvenile). Nine species were recorded from the field plot (Table 1).

2.2. Geostatistic analysis

A spatial autocorrelation analysis was performed on the field data. This analysis used the data set for the two earthworm species, *Lumbricus terrestris* and *Aporrectodea caliginosa*, at two developmental stages. The spatial autocorrelation analysis provides a quantitative estimate of the spatial correlation between the two samples as a function of their separation distance (Isaaks and Srivastava, 1989). The spatial analysis used the semivariance estimated by:

\[
\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)^2]
\]

where \(N(h)\) is the number of sample pairs at each distance interval \(h\) and \(Z(x_i)\) and \(Z(x_i + h)\) are the values of the variable at any two places separated by a distance \(h\). The resulting graph of semivariance versus different lag distances is called the experimental semivariogram (Fig. 1). The lag \(h\) is defined as a vector with both distance and direction. In practice, the direction effect was considered by computing experimental variograms according to different directions of the \(h\) vector. The resulting graphs were compared, and no significant differences indicate that the field plot may be considered isotropic. The spatial structure of the data is determined by fitting a mathematical model to the experimental semivariogram. The model is fitted by means of a least square method. Kriging is used as an interpolating method based on spatial structure. Field maps are produced by ordinary block kriging with an elementary block size of 1 m². Geostatistical analyses are performed using GS+$^\copyright$ (Gamma Design Software, 1994).

The spatial distribution of earthworm biomass was compared with soil hydromorphic properties obtained from a standard soil survey. The soil was a loamy brown leached to a depth of more than 2 m, the slope value was estimated to 1%.

<table>
<thead>
<tr>
<th>Species</th>
<th>Ecological type</th>
<th>Biomass</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Lumbricus castaneus</em> (Savigny, 1826)</td>
<td>epigeic</td>
<td>0.4</td>
<td>1</td>
</tr>
<tr>
<td><em>Aporrectodea giardi</em> (Ribaucourt, 1900)</td>
<td>anecic</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td><em>Lumbricus terrestris</em> (Linne, 1758)</td>
<td>anecic</td>
<td>72</td>
<td>52</td>
</tr>
<tr>
<td><em>Alotholophora chlorota chlorotica typica</em> (Savigny, 1826)</td>
<td>endogeic</td>
<td>56.4</td>
<td>23</td>
</tr>
<tr>
<td><em>Alotholophora chlorota chlorotica Albinica</em> (Savigny, 1826)</td>
<td>endogeic</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><em>Alotholophora rosea</em> (Savigny, 1826)</td>
<td>endogeic</td>
<td>1.8</td>
<td>10</td>
</tr>
<tr>
<td><em>Alotholophora icerica</em> (Savigny, 1826)</td>
<td>endogeic</td>
<td>0.7</td>
<td>2</td>
</tr>
<tr>
<td><em>Aporrectodea caliginosa</em> (Savigny, 1826)</td>
<td>endogeic</td>
<td>40.4</td>
<td>148</td>
</tr>
<tr>
<td><em>Octalasium cyaneum</em> (Savigny, 1826)</td>
<td>endogeic</td>
<td>0.3</td>
<td>0.5</td>
</tr>
</tbody>
</table>
3. Results

3.1. Variograms

The directional variograms (0°, 45°, 90° and 135°, Fig. 2) computed for the two species showed an anisotropy of their spatial distribution. For *L. terrestris* (adults and juveniles) and adult *A. caliginosa* directional variograms (Fig. 2(a)–(c)) presented common sills but different ranges. This is a geometric anisotropy expressing the same degree of spatial continuity for different ranges. In its simplest form, geometric anisotropy is akin to elliptically shaped zones wherein the data values are correlated, that is, zones ‘stretched’ in the directions of the maximum range (Rossi et al., 1992). The variograms suggested that the spatial continuity was minimal in the 0° direction that corresponds to the field slope and maximal for the 90° direction. The directional variograms for *A. caliginosa* juveniles (Fig. 2d) exhibited the same anisotropy but without any sill: there is a linear trend that gives an increasing shape to the variogram as separation distance increases.

All earthworm species (adults and juveniles) were spatially autocorrelated at field scales for distances of...
Table 2
Variogram model parameters for the two studied species across the site. \( C_1/(C_0+C_1) \) = relative structural variance. \( A_1 \) = range parameter for the major axis (0°) and \( A_2 \) = range parameter for the minor axis (90°). \( r^2 \) = coefficient of determination between model fitted and experimental variogram. \( S^2 \) = sample variance for variates.

<table>
<thead>
<tr>
<th>Earthworms biomass of</th>
<th>Model fitted</th>
<th>( C_0 )</th>
<th>( C_1/(C_0+C_1) )</th>
<th>( A_1 )</th>
<th>( A_2 )</th>
<th>( r^2 )</th>
<th>( C_1 )</th>
<th>( S^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>L. terrestris adults</td>
<td>Spherical(^a)</td>
<td>72</td>
<td>0.81</td>
<td>28.39</td>
<td>66.02</td>
<td>0.902</td>
<td>303.8</td>
<td>249.3</td>
</tr>
<tr>
<td>A. caliginosa adults</td>
<td>Spherical(^a)</td>
<td>19.6</td>
<td>0.86</td>
<td>29.73</td>
<td>63.18</td>
<td>0.881</td>
<td>120.7</td>
<td>98.7</td>
</tr>
<tr>
<td>L. terrestris juveniles</td>
<td>Gaussian(^b)</td>
<td>140</td>
<td>0.82</td>
<td>18.11</td>
<td>37.73</td>
<td>0.944</td>
<td>639.4</td>
<td>426.5</td>
</tr>
<tr>
<td>A. caliginosa juveniles</td>
<td>Linear(^c)</td>
<td>10.5</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.941</td>
<td>—</td>
<td>102.2</td>
</tr>
</tbody>
</table>

\(^a\) \( \gamma(h) = C_0 + C_1[1.5(h/A) - 0.5(h/A)^3] \) for \( h \leq A \).
\(^b\) \( \gamma(h) = C_0 + C_1 \) for \( h > A \).
\(^c\) Note that this model is not positive definite and could not be used for kriging.

Fig. 3. Bock kriging maps of earthworm biomass (\( (a) = L. \) terrestris adults; \( (b) = A. \) caliginosa adults; \( (c) = L. \) terrestris juveniles: \( Z \) in g m\(^{-2}\)) and soil hydromorphic characteristics (\( 1 = \) no hydromorphy; \( 2 = \) low hydromorphy in the upper layer; \( 3 = \) high hydromorphy in the upper layer).
about 20 and 60 m (the ranges must be approximate because 100 values are low when an anisotropy is detected). The ranges were higher for the adult stages. Variograms of *L. terrestris* adults and juveniles and *A. caliginosa* adults (Fig. 2(a)–(c)) suggest that the structural component of sample population variance was approximately 80–85% (Table 2). This result shows a high spatial dependence in this field.

### 3.2. Kriging maps

Maps of the spatial distribution of biomass (Fig. 3) over the whole area were computed. The distributions of adult stages showed similar general trends (Pearson correlation coefficient $r=+0.56$) and were strongly related to soil hydromorphy. Two kinds of patch were observed: (i) in the northeastern part corresponding to a well-drained area, a high-biomass patch with from 53 to 64.5 g m$^{-2}$ *L. terrestris* and from 40 to 48 g m$^{-2}$ *A. caliginosa*, (ii) in the southwestern part corresponding to a highly hydromorphic area, a low-biomass patch, with from 10 to 20 g m$^{-2}$ *L. terrestris* and from 10 to 17 g m$^{-2}$ *A. caliginosa*. The distribution of *L. terrestris* juveniles was quite different from that of the adult stage and was not related to soil hydromorphic properties: a relatively large high-biomass patch occurred in the centre of the area.

### 4. Conclusions

Geostatistics showed that the biomass distributions of *L. terrestris* adults and *A. caliginosa* adults were correlated in the field. This result contrasts with the observations of Poier and Richter (1992) in an arable loess soil. In our study, the two observed spatial distributions were highly related to a hydromorphic gradient. By contrast the biomass distribution of *L. terrestris* juveniles is not dependent on this factor. The biomass range was high (maximum 80 g m$^{-2}$ for the *L. terrestris* juveniles). This observation suggests that high variation in earthworm biomass could greatly modify soil structure at the field scale. These modifications would induce local changes in soil functioning (e.g. porosity, incorporation of organic matter).

These preliminary results will be extended using other spatial statistical tests including cross-vario-grams and mantel tests to assess the joint spatial dependence between co-occurring organisms or between organisms and environmental factors.

### References


