Origin of spatial structures in ecology

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Outline of the presentation

1. Setting the stage
2. Spatial variation
3. Importance of the scale of the observations
4. Two types of spatial processes
5. Reference

Origin of spatial structures
Landscape ecology studies the spatial variation of species composition throughout landscapes. That variation is called beta diversity.

Landscape genetics studies the spatial variation of the genetic structure of individuals or local populations throughout landscapes.
Ecologists want to understand and model spatial [or temporal] community structures through the analysis of **species assemblages** observed at georeferenced sampling sites.

- For an ecologist, species assemblages are the best response variable available to estimate the impact of [anthropogenic] changes in ecosystems.

- **Difficulty:** species assemblages form **multivariate data tables** (sites x species).

Likewise, landscape geneticists analyse multivariate genetic data describing individuals or local populations observed at georeferenced sampling sites.

*Origin of spatial structures*
In ecology, **beta diversity** is the (spatial) variation in species composition among sites.

**Temporal beta diversity** is the variation in species composition among observations of a site through time.

Likewise, **beta genetic diversity** describes the (spatial) genetic variation among sites on the map.

Beta diversity is not random; it is organized in natural communities. It displays **spatial structures**.
Ile Callot, Finistère.
Photo P. Legendre
3. Importance of the scale of the observations

In the previous slide, the distribution of daisies seemed *random* at the scale the picture was taken.

⇒ Our perception of the spatial structures varies with the scale of the observations.
Non-random, highly organized distribution of organisms.

Stonehenge, Wiltshire, southern England.
Photo P. Legendre
Drawing representing the structure of the Stonehenge megalithic monument.

Photo by PL of a panel shown on the Stonehenge site.
4. Two types of spatial processes

Spatial structures in communities indicate that some process has been at work to create them. Two families of mechanisms can generate spatial structures in communities.
Google Maps
Spatial structures in communities indicate that some process has been at work to create them. Two families of mechanisms can generate spatial structures in communities:

- **Induced spatial dependence:** forcing (explanatory) variables are responsible for the spatial structures found in the species assemblage. They represent environmental or biotic control of the species assemblages, or historical dynamics. The spatial structures are generally broad-scaled.

- **Community dynamics:** the spatial structures are generated by the species assemblage themselves, creating autocorrelation$^1$ in the response variables (species). Mechanisms: *neutral processes* such as ecological drift and limited dispersal, *interactions* among species. Spatial structures are generally fine-scaled.

$^1$ *Spatial autocorrelation* (SA) is technically defined as the dependence, due to geographic proximity, present in the residuals of a [regression-type] model of a response variable $y$ which takes into account all deterministic effects due to forcing variables. Model: $y_i = f(X_i) + SA_i + \epsilon_i$. 
Successive filters block species and differentiate species assemblages

Neutral theory

Regional species pool
Random sampling filter
Abiotic filter
Biotic interaction filter
Local species assemblage

Niche theory (species sorting)
Five cases illustrating the origin of spatial structures through different types of relationships between an explanatory variable $x$ and a response variable $y$ observed across space.

Modified from Fortin & Dale (2005)

Case 1: Null situation

Four ponds (large circles) connected by a stream.
A light current is flowing from left to right in some cases.
Case 1: Null situation

\[ w_x = 0 \]
\[ w_y = 0 \]

Representing of this process in a simulation program:
\[ y_j = \varepsilon_j \] where the \( \varepsilon_j \) are iid random normal deviates

\( iid \) : independent and identically distributed
Case 1: Null situation

\[ x_{j-2} \quad w_x = 0 \quad x_{j-1} \quad w_x = 0 \quad x_j \quad w_x = 0 \quad x_{j+1} \]

\[ y_{j-2} \quad w_y = 0 \quad y_{j-1} \quad w_y = 0 \quad y_j \quad w_y = 0 \quad y_{j+1} \]

\[ y_j = \varepsilon_j \]

Case 2: \( y \) depends on \( x \)

\[ x_{j-2} \quad w_x = 0 \quad x_{j-1} \quad w_x = 0 \quad x_j \quad w_x = 0 \quad x_{j+1} \]

\[ y_{j-2} \quad w_y = 0 \quad y_{j-1} \quad w_y = 0 \quad y_j \quad w_y = 0 \quad y_{j+1} \]

\[ y_j = \beta_0 + \beta_x x_j + \varepsilon_j \]

Origin of spatial structures
Case 1: Null situation

\[ x_{j-2} \rightarrow x_j \rightarrow x_{j+1} \]
\[ y_{j-2} \rightarrow y_j \rightarrow y_{j+1} \]

\[ w_x = 0 \]
\[ w_y = 0 \]

Case 2: \( y \) depends on \( x \)

\[ x_{j-2} \rightarrow x_{j-1} \rightarrow x_j \rightarrow x_{j+1} \]
\[ y_{j-2} \rightarrow y_{j-1} \rightarrow y_j \rightarrow y_{j+1} \]

\[ w_x = 0 \]
\[ w_y = 0 \]

\[ \beta \]

Case 3: SA in \( y \)

\[ x_{j-2} \rightarrow x_{j-1} \rightarrow x_j \rightarrow x_{j+1} \]
\[ y_{j-2} \rightarrow y_{j-1} \rightarrow y_j \rightarrow y_{j+1} \]

\[ w_x = 0 \]
\[ w_y = 0 \]

\[ \beta \]

Case 4: Induced spatial dependence

\[ x_{j-2} \rightarrow x_{j-1} \rightarrow x_j \rightarrow x_{j+1} \]
\[ y_{j-2} \rightarrow y_{j-1} \rightarrow y_j \rightarrow y_{j+1} \]

\[ w_x = 0 \]
\[ w_y = 0 \]

\[ \beta \]

Water flow

\[ y_j = w_y y_{j-1} + \varepsilon_j \]

\[ x_j = w_x x_{j-1} + \zeta_j \] spatial autocorrelation in \( x \)

\[ y_j = \beta_0 + \beta_x x_j + \varepsilon_j \] spatial dependence of \( y \) on \( x \)
Case 5: SA in $\mathbf{x}$ and $\mathbf{y}$, $\mathbf{y}$ depends on $\mathbf{x}$

\[ x_j = w_x x_{j-1} + \xi_j \]  
spatial autocorrelation in $\mathbf{x}$

\[ y_j = \beta_0 + \beta_x x_j + w_y y_{j-1} + \epsilon_j \]  
spatial dependence and autocorrelation in $\mathbf{y}$
How can we determine the relative influences of induced spatial dependence (environmental forcing) and of community dynamics?

These two processes usually generate spatial structures in communities that have different spatial scales. The signature of environmental forcing is very often at larger spatial scale than that of community dynamics.

To answer the question, we will have to conduct analyses at different spatial scales.

How to do that will be explained in the course chapter entitled “Spatial eigenfunction modelling”.

Origin of spatial structures
5. Reference


Origin of spatial structures
End of the presentation

Origin of spatial structures