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# The effects of the landscape pattern on arthropod assemblages : an analysis of scale-dependence using satellite data

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## Abstract

Forest fragmentation induces changes in abundance and species richness in many insect groups. The main objective of the present paper was to study the effects of the landscape pattern on arthropod assemblages, by means of developing spatial indices derived from satellite imagery. We also performed an analysis to identify at which scale the forest structure plays the main role on ecological variables. We chose two arthropod assemblages to test our hypothesis : riparian Collembola sampled in the Massif of Arize (French Pyrenees) and terrestrial arthropods sampled in the island of Minorca (Spain). Landsat TM images covering the area of test sites were used to derive the Normalised Difference Vegetation Index (NDVI) and land cover classifications. We calculated spatial indices in a square window of increasing sizes over the digital numbers of processed images. Univariate and multiple regression analysis between entomological data and spatial indices were computed at each window size. The scalar analysis allowed us to conclude that : 1) the species richness, the percentage of endemism and the species composition varied with landscape pattern at different scales; 2) the species richness of collembolan communities in the Arize massif was less affected by spatial structure than the species richness of terrestrial arthropod assemblages of Minorca. However, the hierarchical cluster analysis showed that species composition of riparian communities was constrained by the spatial pattern, especially at local scales and in a narrow range of scales. And 3) the proportion of endemisms was higher on homogeneous and natural areas. The satellite data were able to provide information on the landscape pattern relevant to the conservation of the biodiversity and the endemic biota.

**Keywords** : Spatial indices, habitat fragmentation, NDVI, endemism, biodiversity.

## Introduction

There is now a solid body of empirical work demonstrating that forest fragmentation induces changes in abundance and species richness in many insect groups (DIDHAM *et al.*, 1996; ROLAND & TAYLOR, 1997). The main parameters affecting biotic communities in forest fragments are : area, degree of isolation, edge effects, patch shape and connectivity (MURCIA, 1995). The classical approach is therefore to study the landscape at patch level. In fact, the patch level approach is based on the theory of island biogeography (MACARTHUR & WILSON, 1967) applied to the landscape, i.e. considering forest fragments as islands surrounded by an "inhospitable" environment such as agricultural land. The term *patch* typically implies a discrete and internally homogeneous entity, yet such patches are rarely observed in nature. Instead, hierarchical mosaics of patches within patches occur over a broad range of scales (KOTLIAR & WIENS, 1990). Thus, the mentioned comparison becomes simplistic because it does not take into account the heterogeneity of the habitat. As stated by ANDRÉN (1994), another important component for the presence of a species in a patch is not only its heterogeneity, size and isolation, but also the neighbouring habitat.

The first objective of the present paper was to study the effects of the landscape pattern on diversity and on endemism of arthropod assemblages, by means of developing a set of spatial indices that integrate the main fragmentation components from satellite images. We characterised the landscape pattern integrating the heterogeneity within a patch with that of the neighbouring habitat. To define the extent of the neighbouring habitat, it is necessary to examine the effects of scale on the landscape measurements. Thus, the second objective was to identify at which scale the forest structure explains most of the variance in ecological variables (species richness, percentage of endemism and species composition).

To achieve our objectives we chose two study areas : in the Massif of Arize (Ariège, French Pyrenees), riparian Collembola were sampled in thirty-five stations; and in Minorca (Balearic Islands, Spain), terrestrial arthropods were sampled in twenty-two stations. We sampled at homogeneous conditions in order to separate the role of the micro-habitat from that of the landscape structure on biodiversity measures. For Collembola we restricted the sampling to riparian communities; for terrestrial arthropods we restricted the sampling to shrubs and trees. The aim of this paper was to apply a same methodology to test the hypothesis of scale-dependence of biodiversity patterns, as expressed by ANDRÉN (1994), on two widely different cases.

## Material and methods

### Study areas

The Massif of Arize are mountains of moderate elevation (maximum 1715 m above sea level) located in the Northern part of the French Pyrenees. It ranges over 40 km long from east to west. Natural vegetation comprise beech forests (*Fagus sylvaticus*), above 1000 m, and woods of different deciduous species dominated by oaks, below 1000 m. Since 1965 large parts of this forest have been cleared and replaced by stands of exotic conifers. At present, pastures, agricultural land and little villages surround the natural and artificial forests of the Massif.

The Biosphere Reserve of Minorca island is a well-preserved rural and natural landscape. MÉDAIL & QUÉZEL (1997) classified it as a Mediterranean "hot-spot", i.e. a sector with an exceptional concentration of species and a high rate of endemism. Located in the Western Mediterranean, it has an area of 700 km$^2$. The potential vegetation of Minorca comprises two main communities (BOLÓS et al., 1970) : a forest community dominated by holm oak (*Quercus ilex*) and related shrubland, and a shrubland community characterised by wild olive (*Olea europea* var. *Sylvestris*), which is adapted to dryer conditions. Long ago, the two original plant communities were gradually shifted to pine woodland and pastures. At present, pastures and agricultural land surrounded by semi-natural vegetation cover most of the island surface, thus constituting a typical Mediterranean rural landscape.

### Entomological data

In the Massif of Arize, riparian Collembola were sampled in thirty-five stations during the years 1992, 1993 and 1998, ranging from 400 m to 1400 m of elevation (DEHARVENG & LEK, 1995). The stations were located in humid habitats of beech forest, deciduous wood or conifer plantations. Fauna was extracted over 7 to 10 days in the laboratory, using Berlese-Tullgren apparatuses. Taxonomic identification of Collembola was at the species level. Three ecological variables were selected : species richness, the percentage of endemism (i.e. the number of species endemic to the Pyrenees or to a part of the Pyrenees, divided by the total number of species in the sample), and the dissimilarity among samples (i.e. species composition distance).

In Minorca, terrestrial arthropods were sampled in twenty-two stations during final summer of 1997 (unpublished data), by sweeping over plants in a square area of 10 m × 10 m and during 90 minutes. The stations were located in different vegetation formations : mixed woods (pine and holm oak), holm oak woods, open shrubland and closed shrublands (wild olive). The fauna was classified at morphospecies level from twenty taxonomic units : Acarina, Araneae, Blattodea, Coleoptera, Collembola, Diptera, Embioptera, Heteroptera, Homoptera, Hymenoptera, Isopoda, Microcoryphia, Myriapoda, Neuroptera, Orthoptera, Phasmida, Pseudoscorpionida, Psocoptera, Thysanoptera, Trichoptera. Since the classification was at morphospecies level, the percentage of endemism and the dissimilarity among samples could not be computed, so only one ecological variable was selected : species richness.

As a preliminary study, we tested the dependence of species richness and the percentage of endemism on different vegetation formations -discriminated on the terrain- in an analysis of variance (ANOVA).

**Remote sensing data and statistical analysis**

Two high-resolution optical images covering the area of test sites were used, based on those acquired on 13th of July in 1990 (Arize) and 20th of July in 1992 (Minorca) by Landsat TM satellite. We used the infrared and red bands to derive the Normalised Difference Vegetation Index (NDVI). This vegetation index gives a measure of the photosynthetic active biomass, and also allows to highly mitigate the effect of shadows in radiometric response (COLBY, 1991). Land cover data of Minorca was previously derived by means of a supervised classification into 6 categories with a global accuracy of 77% (CHUST, 1997) : shrubland (open and closed shrubland), woodland (holm oak and pine), agricultural land (non irrigated agriculture and pasture), irrigated land, unproductive ground (urban areas, bare ground and rocky habitats) and water surfaces. The classification was performed with the maximum likelihood procedure (EASTMAN, 1991), using the six original bands of 30 m resolution.

The calculus of spatial indices was performed in a square window of $n \times n$ pixels (where $n$=3, 5, 7, ..., 69) over the Digital Numbers (DN) of the NDVI map and of the land cover classification. The window was centred in the sample station. Given that a pixel of TM images has a 30 m size, the highest quadrat (69 × 69 pixels) equals to 4.28 $km^2$. We chose this maximum extent to avoid a high overlapping among sample stations. We calculated three spatial indices over the NDVI map for the two sites :

1. Mean (M), in our case it gives a measure which is related with the vegetation cover.
2. Standard Deviation (SD), as a measure of heterogeneity.
3. Angular Second Moment (ASM), as a measure of homogeneity :

$$ASM = \sum_i \sum_j [p(i,j)]^2$$

where p(i,j) is the co-occurrence probability (HARALICK *et al.*, 1973). While SD does not take into account the neighbourhood of the pixels, ASM measures the different arrangement of pixels within the window, so ASM incorporates a spatial component in contrast with SD.

We calculated two other spatial indices for the image of Minorca, based on terrain data :

4. Mean Distance (MD), it is a measure of the difference between the mean of NDVI values, corresponding to the land cover of the sample station ($\overline{Y}$), and the digital numbers (of NDVI map) in the window :

$$MD = \frac{\sum_i \left| DN_i - \overline{Y} \right|}{N}$$

where $DN_i$ is the DN of a pixel $i$ in the window, and N is the total number of pixels in the window.

5. Land Cover Proportion (LCP), it is the number of pixels belonging to the land cover of the sample station divided by the total number of pixels in the window.

The possible linear relation between entomological data and spatial indices was analysed by Pearson's correlation coefficient along the scalar spectrum. This kind of analysis was, for instance, applied by JØRGENSEN & NØHR (1996) to establish the correlation between the number of bird species and landscape diversity indices. For those entomological variables significantly correlated with more than one spatial index, we performed a multiple regression analysis at each scale.

Hierarchical cluster analysis was used to calculate the dissimilarities among samples of the Massif of Arize, corresponding to species composition, land-scape patterns and the geographic position, by means of the Euclidean distance. The landscape dissimilarities were determined by taking the spatial indices as variables (mean, standard deviation and ASM) and creating one dissimilarity matrix for each window size. The possible linear relation between dissimilarities of the species composition and of the landscape structure was analysed by Pearson's correlation coefficient at each window size. Finally, we tested the linear correlation between dissimilarities of the species composition and the geographic distance.

## Results

The analysis of variance (Table 1) showed that species richness of the two test sites and the percentage of endemism of Collembola (Arize) did not depend on different vegetation types discriminated on the terrain.

Table 1. Probability values from the analysis of variance to test the difference of means of the variables (species richness and percentage of endemism) in respect to the vegetation formations discriminated on the terrain.

| | Arize | Minorca |
|---|---|---|
| Species richness | 0.286 | 0.216 |
| Percentage of endemism | 0.305 | - |

The coefficients of correlation, between ecological variables and spatial indices at different scales, are shown in Figs 1-2. The significance level was selected at the 0.05 probability. We list the results for each spatial index. *Mean* : Species richness of the two test sites and the percentage of endemism of Collembola (Arize) were not significantly correlated with the mean of NDVI values at any scale. *Standard deviation* : Species richness of terrestrial arthropods, Minorca, was negatively correlated with standard deviation for large scales (from window size 29×29 to 69×69 pixels). In other words, the number of species was low when the regional landscape was heterogeneous. Riparian Collembola were not correlated with standard deviation. *Angular second moment* : Species richness of terrestrial arthropods was positively correlated with ASM for large scales (from 31×31 to 57×57 pixels). Similarly at the result of standard deviation, the higher the homogeneity of regional landscapes, the greater the number of species. For riparian Collembola, only the degree of endemism was correlated with ASM for the following range of scales : from 9×9 to 15×15 pixels and from 31×31 to 67×67 pixels; the highest degree of endemic species were, then, found in homogeneous areas. *Mean distance* : Species richness of terrestrial arthropods was positively correlated with MD at local scales (from 3×3 to 15×15 pixels); the number of species was high when the nearest environment was different of the station environment. *Land cover proportion* : Species richness of terrestrial arthropods was negatively correlated with LCP at local scales (from 3×3 to 23×23 pixels); as for the result of MD, the number of species was low when nearest land covers are the same as the station land cover.

As only species richness of terrestrial arthropods were significantly correlated with more than one spatial index, we performed the multiple regression analysis between this variable and mean, standard deviation, angular second moment, mean distance and land cover proportion (Fig. 3). The multiple coefficient of correlation (R) showed two significant regions along the scale spectrum, one at local scales (from 3×3 to 17×17 pixels) and the other one at regional scales (from 33×33 to 69×69 pixels). At local scales, the main contribution is from the mean distance and land cover proportion. At regional scales R mainly depends on the standard deviation (in negative sign) and on the angular second moment (in positive sign). This suggests that high number of species would be found in landscapes characterised by heterogeneous nearest environments and by homogeneous environments at larger scales.

The coefficients of correlation, at the significance level of 0.05, between dissimilarities of species composition and of landscape patterns are shown in Fig. 4. The positive correlation between these two variables was statistically significant for all scales, presenting a narrow peak at the scale range from 5×5 to 9×9 pixels. At this peak, landscape dissimilarities explained 45% of the variance. This suggests that species composition was structured particularly by landscape patterns at local scales. The correlation between species composition dissimilarities and geographic distances among samples was low (r=+0.28), but still significant.

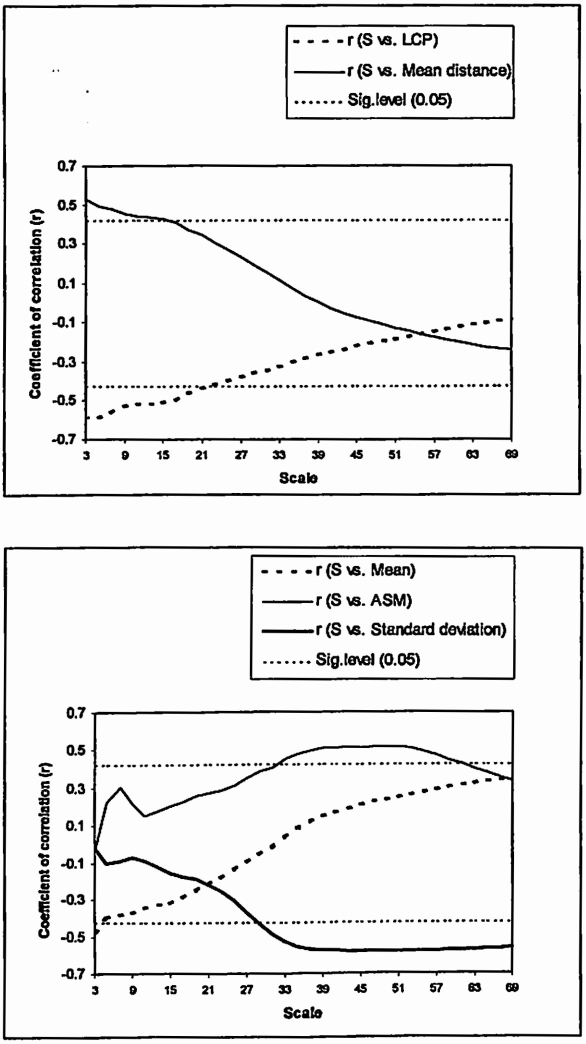


Fig. 1. The coefficient of correlation (r), between the species richness (S) of terrestrial arthropods (Minorca) and spatial indices, is plotted *versus* scale (in pixel units of window size).

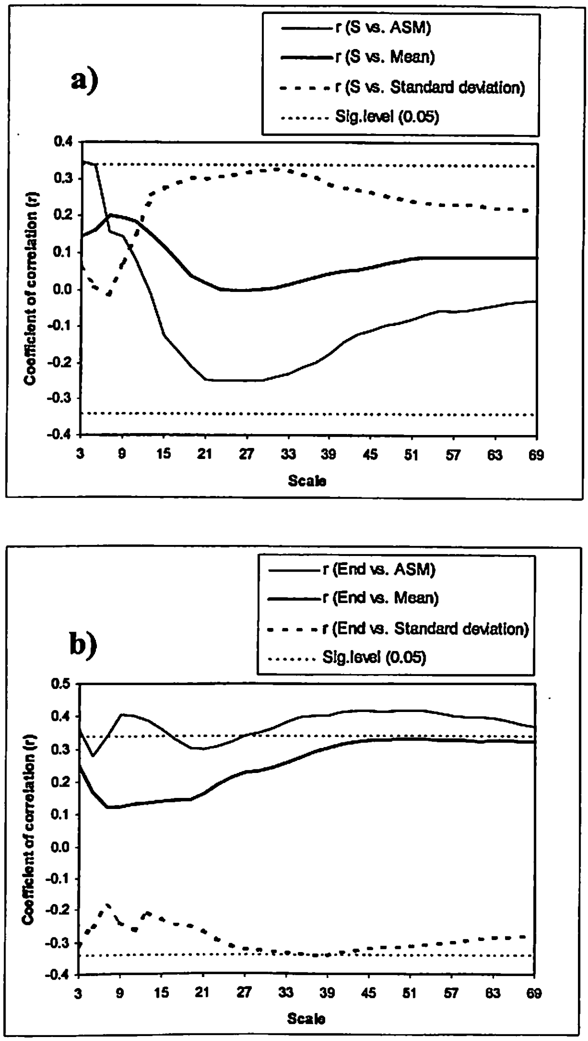


Fig. 2. The coefficient of correlation (r) is plotted *versus* scale (in pixel units of window size) for riparian Collembola (Massif of Arize). A) The coefficient of correlation corresponds to the species richness (S) *versus* spatial indices. B) The coefficient of correlation corresponds to the percentage of endemism (End) *versus* spatial indices.

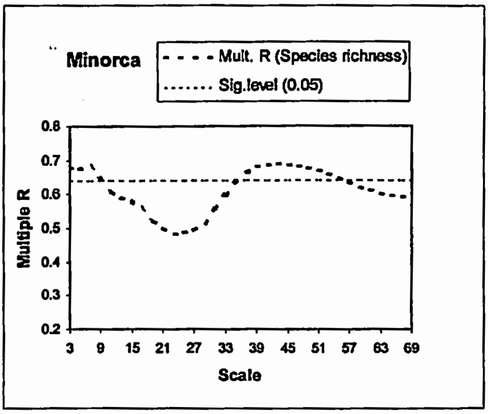


Fig. 3. The multiple coefficient of correlation (R), between species richness (S) of terrestrial arthropods (Minorca) and spatial indices, is plotted *versus* scale (in pixel units of window size).

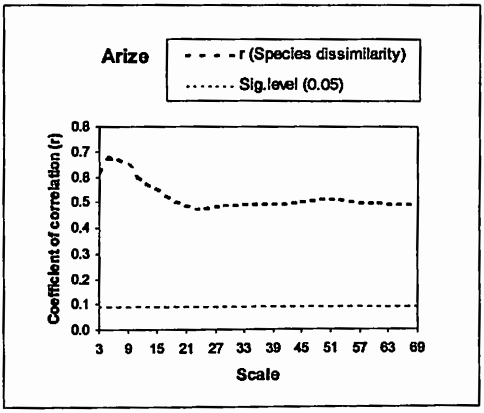


Fig. 4. The coefficient of correlation (r), between dissimilarities of Collembola species (Arize) and dissimilarities of the landscape structure, is plotted *versus* scale (in pixel units of window size).

## Discussion and conclusion

The results showed that the species richness, the percentage of endemism and the species composition responded to the landscape structure at different spatial scales. The species richness of terrestrial arthropods, in Minorca, were sensitive to two scale ranges of landscape; a high number of species were found at the landscapes characterised by heterogeneous nearest environments and by homogeneous environments at larger scales. The scalar behaviour of species richness suggests that the landscape is hierarchically structured into two levels which influence the ecology of arthropods.

On the other hand, species richness of riparian Collembola was not correlated with spatial indices; this could be due to riparian communities being less affected by the spatial structure of the vegetation at the tested scale (our landscape element is the pixel, of 30 m size). This result is an invitation to explore the fact that different biological categories may behave differently to habitat fragmentation. The degree of endemism was higher on homogeneous landscapes which are located in natural forests in the Massif of Arize. In fact, the heterogeneous areas of the human-influenced landscapes, such as Minorca and Arize, are correlated with village and pasture proximity, and therefore the forest fragments could be younger, more human-frequented and with pasture. It is known that these factors influence biodiversity (HUSTON, 1994). So, we must be cautious in interpreting the correlations that we found as a cause-effect relationship.

The hierarchical cluster analysis revealed that species composition of collembolan communities were more constrained by the spatial pattern than by the geographic distance. The effect of the spatial structure was especially strong at local scales and in a narrow range of scales; an area of approximately 105 m radium constituted the region that mainly structured the collembolan communities of humid habitats. As an environmental strategy, it could be suggested from the present data that riparian communities would need a minimum distance of a hundred metres of natural vegetation, from the water and along the stream, to maintain the native species. However, it still remains to test whether this critical region would have the same size for a different resolution maps, e.g. using the Compact Airborne Spectrographic Imager (CASI), SPOT Panchromatic with a 10 m resolution, or aerial photographs in numerical format.

Recent papers also reported the effects of the landscape structure on different animal communities. ROLAND & TAYLOR (1997) found that insect parasitoid species responded to forest structure at different spatial scales; JØRGENSEN & NØHR (1996) reported the influence of landscape elements, detected by satellite images, on the number of bird species. The spatial predictability of bird populations, using remote sensing data, was tested by several authors (LAUGA & JOACHIM, 1992; HERR & QUEEN, 1993; HEPISNTALL & SADER, 1997; CASUCCI *et al.*, 1998). Habitat and food availability maps of mammals were generated from satellite data using GIS (ORMSBY & LUNETTA, 1987; PEREIRA & ITAMI, 1991). However, the authors estimated the population levels or biodiversity in different vegetation types and in a broad range of land covers. The contribution of the present paper is to study the effect of sampling within homogeneous conditions in order to separate the role of the micro-habitat from that of the landscape structure on biodiversity. We restricted the sampling of Collembola to riparian communities; for terrestrial arthropods, we restricted the sampling to shrubs and trees. We did not find significant differences on species richness of the two test sites for each vegetation type discriminated on the terrain. This suggests that species richness of terrestrial arthropods per unit of area depend, among other factors, on the landscape structure of the neighbouring habitat, supporting the idea of ANDRÉN (1994).

Finally, the satellite data were able to provide information on the landscape pattern which partially explain important biotic parameters of arthropod and collembolan communities, such as species richness, the degree of endemism and the species composition. Such approaches could be used in the future for mapping biological diversity by interpolating a multiple regression model to all pixels of the image.

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