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Spatial uncertainty effects on a species-landscape relationship model in ecology

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Abstract

In this study, we explore the effects of geometrical uncertainty in an existing species-landscape relationship model in the hoverfly communities. We also investigate how geometrical uncertainties affect a more complex model including both current forest patch features and past forest features. Because of a possible time-lag in biological responses to forest changes such as fragmentation, the historical dimension is added to the first model. The proposed approach relies on three spatial sources enabling to get forest fragments at different times: historical map (~1850), aerial black and white photographs (1954) and orthorectified photographs (2010). Firstly, we analyze the effect of the spatial data production method (manual versus automatic) on models using current forest patches only. Then, we build a more complex model including past changes in forest size. As previously, the effect of production-based uncertainty was assessed by comparing the models based on forests extracted manually and automatically. We address finally the impact of positional accuracy on the historical map by using a Monte Carlo simulation approach. Global results show that responses of the statistical models are strongly affected by spatial uncertainty in inputs.

Keywords: species-landscape relationship, geometrical uncertainty, historical map

1. Introduction

Habitat fragmentation is one of the main processes that affect biodiversity in landscapes (Saunders *et al.*, 1991). This process implies several effects on habitats such as the reduction of patch sizes and the increase in isolation of patches (Fahrig, 2003). The consequences of fragmentation on biodiversity vary according to the species. Taxa with a weak mobility are more affected than the species with a high capacity of dispersion such as birds or mammals.

Landscape metrics are frequently used to quantify habitat fragmentation (McGarigal, 2002; Digiovinazzo *et al.*, 2010). These metrics can consider both changes in composition and configuration of the spatial patterns (Long *et al.*, 2010). These metrics are then associated with some biodiversity response variables (such as species richness or abundance) to build pattern/process relationships-based models.

While the question of habitat fragmentation and its effect on biodiversity is a key topic in landscape ecology (Fahrig, 2003, Ewers and Didham, 2006), the influence of uncertainty in spatial data on ecological models is rarely addressed (Rocchini *et al.*, 2011; Lechner *et al.*, 2012; Moudry and Simova 2012). The potential effect of spatial errors is well-recognized by ecologists (Jager and King, 2004; Barry and Elith, 2006) but is often ignored on the outcome of analysis (Lechner *et al.*, 2012). However, the

sources of uncertainty in spatial data are numerous. Some of them arise during the production process (e.g. field survey) while others are caused by data processing (e.g. geo-referencing, data transformation) (Leyk *et al.*, 2005).

In this study, we explore the impact of geometrical uncertainties on a Generalized Linear Model (GLM) constructed from hoverfly communities sampled in forest patches. This statistical model widely used in landscape ecology enables to link the number of species collected with area and connectivity of these patches. We also investigate how geometrical uncertainties affect a more complex model including both current forest patch features and past forest features. Because of a possible time-lag in biological responses to forest changes such as fragmentation (Hermy, 1999, Helm and *al.*, 2006, Metzger and *al.*, 2009), the historical dimension is added to the first GLM. In this context where uncertainties arise on each data sources and where the data sources are combined, the spatial errors cannot be longer ignored.

2. Material and methods

The experiments were conducted on a study area located in southwestern France (Long Term Ecological Research site “Vallees et Coteaux de Gascogne”). This is a hilly area (altitude 200-400m) including flood plains and valleys. Wood cover is fragmented and covers some 15% of the area.

Three spatial data sources were used for the study. For current data, forest patches were derived from orthorectified photographs produced by the French mapping Agency (IGN) dating from 2010. For past data, forest patches were extracted on one hand, from old black and white photographs dating from 1954, and on the other hand, from an historical geological survey map drawn from 1818 to 1866 (1:40k). The extraction of forest patches were conducted in two ways: manually (by digitizing) and automatically (Herrault *et al.* 2012). Then, fragment size and connectivity were computed for each forest at each date.

Biological data (Diptera, Syrphidae) were sampled in 2000 (Ouin *et al.* 2006). A total of 3317 adults belonging to 100 species were captured in Malaise traps. This sampling enabled to collect hoverflies in 51 forest fragments. The species were assigned to three ecological groups: non forest species, forest species, and facultative forest species (Ouin *et al.* 2006).

In a first time, we analyzed the effect of the spatial data production method (manual versus automatic) on GLM using current forest patches only. Since the automatic extraction is not free of errors (kappa index = 0.76 for the current forest map), the comparison enabled us to estimate how the production-oriented uncertainty affects the statistical models. If *RS* (specific richness) is the response variable, *AREA* and *CONN* respectively the area and the connectivity of the forest patches, the GLM can be expressed by $RS = a * AREA^b * CONN^c$ where *a* is the intercept and *b, c* the estimates coefficients. Therefore, outcomes to this model depend directly on the spatial inputs and their uncertainty.

In a second time, we built more complex models including past changes in forest size and connectivity, in addition to the current variables, in order to verify a potential role of history on the species richness. As previously, the effect of production-based uncertainty was assessed by comparing the models based on forests extracted manually and automatically.

Finally, we addressed the impact of positional inaccuracies in the historical map on the model response. We used a Monte-Carlo simulation approach to quantify positional errors on each point composing the forest patches (Heuvelink and Burrough, 1993). Positional errors are assumed because of the inherent imperfection of the old source in addition to the georeferencing process. Errors were modeled using a Gaussian distribution with an amplitude that varies for each forest patch. The spatial distribution of positional inaccuracy was derived from kriging interpolation based on independent control points.

3. Results

Global results indicate that spatial uncertainty in inputs tends to strongly affect the response of the species-landscape models. Automatic extraction under-estimates and over-fragments the current forest patches that involve a lower correlation with hoverflies richness than the ones obtained with models based on digitized fragments. As a similar observation, automatic extraction from the historical map leads to underestimate several forest patches in 1850. This affects the significance of change variables based on patches automatically extracted from the historical map. Finally, positional accuracy on the historical map appears as an important factor of uncertainty. Simulations contribute to increase or reduce the forest patch size and therefore distances between fragments which bias the amount of observed changes. Hence, according to the run, the Pseudo R-square varies from 0.65 to 0.75 and the effects of landscape changes strongly fluctuate. For instance, the GLM including landscape dynamics showed that area changes between 1850 and 1954 could have a high significant effect (p-value <0.001) on the response variable while its effect was sometimes non-significant.

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