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Identifying the relevant spatial and temporal scales in plant species occurrence models: The case of arable weeds in landscape mosaic of crops

Audrey Alignier, Benoît Ricci *, Luc Biju-Duval, Sandrine Petit

INRA, UMR 1347 Agroécologie ECOLDUR, BP 86510, F-21000 Dijon, France

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ABSTRACT

Species distribution models (SDMs) represent potential valuable tools to explore factors underlying species occurrence over a large range of spatial scales. However, a recurrent problem with this approach is identifying the appropriate spatial and temporal scales for modeling. This problem is reinforced in plant populations for which it is often difficult to evaluate the limits of habitat patches. In this study, we aimed at developing SDMs for 13 arable weeds in highly dynamic small agricultural region. Although weed dynamic is widely thought to result from local processes, we explored the spatial and temporal scales that would best explain species occurrence over the area. Models were developed using weed occurrence data in 58 fields over four consecutive years (2008–2011) and spatial organization of management practices over the landscape for eight consecutive years (2004–2011). We used a model selection approach based on the minimum AIC criteria to select the best SDMs. Results showed that SDMs can successfully be applied to model weed occurrence over a small region. The appropriate temporal scale to consider in weed SDMs should encompass several years to reflect the effect of management history while the relevant spatial scale should extend beyond the crop field itself and include the field border and neighboring fields. This study illustrates that adopting a multiple scale approach is successful to model plant occurrence over a highly dynamic landscape.

1. Introduction

In recent years, predictive modeling of species distributions has become an increasingly important tool to address various issues in ecology, biogeography, conservation biology and climate change research (Guisan and Thuiller, 2005; Elith and Leathwick, 2009). Among existing tools, niche-based species distribution models (SDM) have proved to be successful in predicting the distribution of plant and animal species over a large range of spatial extents (Guisan and Zimmermann, 2000). SDMs relate various factors – abiotic, biotic, historical and human – to the distribution and abundance of species (Guisan and Zimmermann, 2000). Mapped representations of these factors can be used as explanatory variables to predict species distribution under past, present and future conditions and/or across landscapes, with the different variables (Elith and Leathwick, 2009).

A central and recurrent problem in building SDM is to identify the appropriate spatial scale for modeling (Wiens, 2002). Indeed, it can be difficult to define and therefore map habitat patches, especially for plant species (Freckleton and Watkinson, 2002; Fahrig et al., 2011). In addition, species may exploit space at various spatial scales (Fahrig et al., 2011) and inappropriate selection of spatial scales at which explanatory factors are considered can yield misleading results (Guisan and Thuiller, 2005). In the same way, identifying the appropriate temporal scale for the explanatory variables is critically important. First, some species have been shown to have a delayed response to changes in their environment, e.g., grassland plants respond slowly to habitat fragmentation (Lindborg, 2007), so that there can be a temporal mismatch between species distribution and the factors affecting species persistence (Hanski and Ovaskainen, 2002). The temporal extent and resolution is also a crucial question in SDMs dealing with organisms living in highly dynamic or successional landscapes where suitable habitats appear and disappear more or less predictably. In such landscapes, the turnover of habitats significantly alters the species occurrence from one year to the next and can potentially mask the relationships between explanatory variables and the distribution of species (Hodgson et al., 2009).

Predictive modeling is becoming increasingly relevant in agroecosystems which are highly dynamic landscapes where the agroecological management of pest species and their natural enemies is high on the research agenda, given the shift toward a reduced reliance on pest chemical control (Petit et al., 2003; Vinatier et al.,

* Corresponding author at: INRA, UMR 1347 Agroécologie, 17 rue de Sully, BP 86510, F-21065 Dijon, France. Tel.: +33 3 80 69 33 27; fax: +33 3 80 69 32 22.
E-mail addresses: audrey.alignier@wanadoo.fr (A. Alignier), benoit.ricci@dijon.inra.fr (B. Ricci), luc.biju-duval@dijon.inra.fr (L. Biju-Duval), sandrine.petit2@dijon.inra.fr (S. Petit).

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2009; O'Rourke and Jones, 2011). Among pests that can cause severe crop yield losses, arable weeds remain a major management issue (Park et al., 2003) and the relative contribution of factors that govern their occurrence at various spatial scales is still under debate. The vast majority of existing weed distribution models are mechanistic and aim at identifying the parts of the life cycle of particularly noxious weeds that are key in the patterns of population change (Holst et al., 2007) and how management practices at the field level affect their population dynamics (Sester et al., 2007). Such models aid the design of cropping systems that effectively control weed within the focal field (Bergez et al., 2010; Colbach et al., 2010) and few models have attempted to predict weed distributions over broader spatial extents (Marchetto et al., 2010; Smolik et al., 2010; González-Díaz et al., 2012).

Available empirical studies nonetheless suggest that SDM approaches would be appropriate to model weed distribution as the main factors affecting weed distribution at various scales have been identified, i.e., climate, soil properties (Lososová et al., 2004; Fried et al., 2008), crop type and crop rotation (Bohan et al., 2011) and soil tillage regime (Cardina et al., 2002; Sans et al., 2011). There is however little consensus about spatial and temporal scales at which weed SDMs should be developed. A number of studies suggest that factors acting at spatial scales larger than the crop field itself affect weed species distribution but the relevant spatial extent at which processes occur is less clear (Petit et al., 2012). Perennial habitats bordering crop fields can act as refugia and sources for weeds (Poggio et al., 2010; Cordeau et al., 2011). The 'local' landscape diversity, i.e., adjacent to the focal field, appear to affect the richness of weed communities (Bohan and Haughton, 2012) while at larger scales, i.e., within a radius around a focal field ranging from a couple of hundred meters up to 2 km, landscape composition and structure can affect the distribution of weed species (Gabriel et al., 2005; Gaba et al., 2010; Guerrero et al., 2010) although such effect could not be evidenced in a number of studies (Holzschuh et al., 2007; Marshall, 2009; José-Maria et al., 2010). Therefore, although the relative contribution of local (crop field) versus surrounding environment (field margin, neighboring fields) factors in determining weed species distribution is yet not clear, these results suggest that a relevant spatial scale to model weed distribution might well extend beyond the focal crop field itself.

In terms of temporal extent, weed species may exhibit long-lived seedbanks and unfavorable environmental conditions one year would not impede their emergence the following year (Buhler et al., 1997). Agricultural landscapes are also highly dynamic and can be considered as a shifting mosaic because of crop succession and associated management practices (Steiner and Kölher, 2003). The relationship between the past use of fields and their current suitability for plant species has been well documented in semi-natural habitats (e.g. Gustavsson et al., 2007) but poorly investigated for the vegetation of annual crops. The idea that previous management, associated with the spatial variation in the effectiveness of weed control over years may strongly affect current weed distribution is however common (Cousens et al., 2004) and a recent study has demonstrated that weed richness and biomass can successfully be predicted by the crop rotation of focal fields (Bohan et al., 2011). Such results suggest that accounting for past land management may help predicting the distribution of weed species but the time scale to be considered in SDM remains to be identified.

In this study, our aim is to determine which spatial and temporal scales have to be considered to explain weed species distribution in a highly dynamic landscape mosaics. We developed SDMs to explain the occurrence in fields of 13 contrasted weed species and explored the fit of models as the spatial and temporal scales considered varied. In particular, we hypothesized that (1) the local description of land use into different classes may influence the explanatory power of weed distribution models; (2) the knowledge of management practices over several years improves the explanatory power of weed distribution models; and (3) including information across spatial scales larger than the field itself is needed to develop accurate models of weed occurrence.

2. Materials and methods

2.1. Study area and field selection

Data collection was carried out in a small intensive agricultural region of 890 ha (between 170 and 250 fields depending on the year) located 10 km south of Dijon, France (47°13′N, 5°03′E). The whole area is characterized by low rolling hills, with deep marly soil. We assumed that environmental conditions (soil, weather, landscape characteristics) were rather homogeneous across the study area. Crop species and management practices were recorded from 2004 to 2011 for almost fields in the study area. Within these fields, 58 were selected for weed sampling from 2008 to 2011 (see map in Fig. 1) according to the completeness of management practices information over years. The 58 sampled fields were mainly cultivated with winter wheat (38 ± 11%) and oilseed rape (12 ± 8%) in rotation with spring barley (12 ± 7%) (Appendix 1). Field

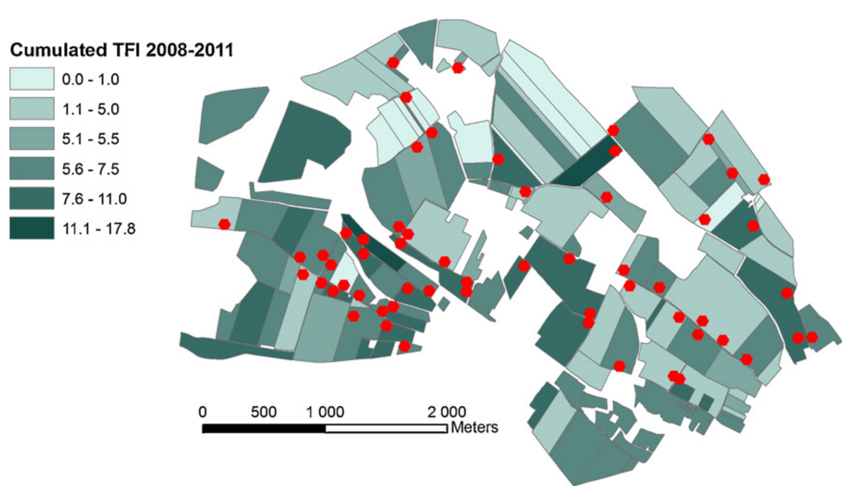

Fig. 1. Position of the 58 surveyed plots (black points) over the Fénay study area. All fields were represented according to their cumulated Treatment Frequency Index (*TFI*) cumulated from 2008 up to 2011.