Impact of farming systems on agricultural landscapes and biodiversity: From plot to farm and landscape scales

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ABSTRACT
Green-way policies in agricultural landscapes focus on ecological continuity between semi-natural elements (hedgerows, permanent grasslands, woods) and landscape heterogeneity. These policies suggest annual crops and temporary grasslands exhibit a negative or neutral impact on biodiversity. However, recent studies indicated the spatial continuities between different crops (spring vs. winter) showed positive impacts on biodiversity. These landscape patterns were directly related to farmers’ decisions regarding the crops cultivated and where the crops were distributed spatially on the farm. The aim of the present study was to evaluate the impacts of different livestock farming system management types on crop patterns and associated biodiversity (carabid beetles) in agricultural landscapes. We combined empirical analyses of farmers’ decision making and ecological data to develop a modeling framework simulating crop allocation and abundance of two different carabid beetle species groups (maize and woody species). Modeling included field, farm, and landscape levels. We simulated different scenarios, where two livestock farming systems, swine and dairy, were combined in different proportions (i.e. number of swine vs. dairy farms) in two agricultural landscapes with varied hedgerow densities. Simulations showed maize carabid species abundance was higher in swine production landscapes due to more frequent spatial continuities between spring and winter crops. In contrast, woody carabid species were more abundant in mixed landscapes (dairy and swine) under high crop diversity. For a given combination of livestock farming systems, simulated landscapes were highly variable in crop acreages and spatial continuities between crops. Our results emphasized the need to manage landscape at a collective level, where crop allocation decisions create more interfaces without modifying livestock farming system combinations.

1. Introduction
Preventing further biodiversity losses in agricultural landscapes is an important social and economic issue, particularly due to societal expectations regarding the provision of ecosystem services, such as pollination and pest regulation from species at risk, e.g. Apis mellifera, Rodolia cardinalis (Kleijn and Sutherland, 2003; Le Roux et al., 2008; Millennium Ecosystem Assessment, 2005). Among the major causes responsible for the decline in biodiversity, habitat fragmentation (corresponding to a reduction in suitable species habitat and increased habitat isolation; Fahrig, 2003) was inarguably identified as a main driver in species extinction (Fahrig, 2003; Krauss et al., 2010; Tilman et al., 2001). The connectivity of remaining suitable habitat fragments — defined as the degree to which the landscape facilitates or impedes species movements (Taylor et al., 1993) — is therefore considered particularly critical for species survival (Fahrig and Merriam, 1985, 1994; Moilanen and Hanski, 1998; Ricketts, 2001).

A variety of green-way policies have been developed and implemented in Europe and elsewhere to promote habitat connectivity in agricultural landscapes through the design of “ecological networks” (Bennett and Mulongoy, 2006). Existing policies primarily focus on the connectivity of semi-natural habitats (hedgerows, permanent grasslands, woods) (e.g. the Natura 2000 network in the EU), which was found crucial for many species survival (Bianchi et al., 2006; Billeter et al., 2008). Under these policies, the “matrix” composed of annual crops and temporary grasslands was expected to result in a negative or neutral impact on biodiversity. Some studies suggested the presence of annual crops with dense cover had a positive impact on woody species (see e.g. Fitzgibbon, 1997; Ouin et al., 2000). The connectivity of annual crops, which serve a role for species using cropped habitats during
their life cycle was also reported, such as pollinators or natural enemies of crop pests (Buret et al., 2013; Maisonhaute, 2010; Varchola and Dunn, 1999; Vasseur et al., 2013). Because biotic and abiotic resources are ephemeral in annual crops, the survival of these species is expected to depend on their ability to colonise new suitable habitats to supplement or complement resources (Dunning et al., 1992). The temporal connectivity of crops, such as winter and spring crops, which offer resources at asynchronous periods, might guarantee supplementation and complementation processes and therefore native species survival (Buret et al., 2013; Vasseur et al., 2013).

Papy (2001) showed annual crop connectivity in agricultural landscapes was directly related to farmers’ decisions regarding the crops cultivated and where the crops were geographically located on the farm. In livestock farms, crop choice was associated with animal feeding management (Papy, 2001). When several animal types were bred and included a dairy herd, the main objective was to produce fodder (i.e. primarily grass and maize) for dairy animals (Garcia et al., 2005). In dairy farms, the diet composition and field spatial organization (distance of fields to farmstead) influenced crop rotation choices (Brunschwig et al., 2006). The main factor determining crop rotation on swine farms was the presence of a feed production facility on the farm (Tersiguel et al., 2012). Tersiguel et al. (2012) reported swine farms grow primarily wheat and maize when feed production facilities were on the farm, whereas swine farms without feed production facilities grow a large diversity of winter crops and less maize. In addition to feed production, crop market prices (Regnold et al., 2011) and manure management (Ramonet et al., 2014) also played a role in crop rotation choices for all farming systems. Crop location on the farm depended on field characteristics, crop management requirements, and distance between field and facilities (Brunschwig et al., 2006; Maxime et al., 1995). The types and diversity of livestock farming systems associated with the field pattern and characteristics on farms might therefore be important drivers of crop surface area and spatial configuration, i.e. crop connectivity. However, to our knowledge, studies have not yet attempted to associate the agronomic drivers of crop patterns on biodiversity, which might be due to the challenges in experimentation on these factors: the farming system is a specific choice of a farmer and cannot be altered. Modeling the agricultural landscape resulting from crop organization by farmers is an alternative. Several landscape models have been developed in recent years, mainly based on statistical inferences (Dury, 2011). The models are largely derived from data mining of land cover databases, where the farm level is lacking. This implies the models cannot integrate an explicit representation of a cropping plan decision rule at the farm level. Some models include the possibility to define several groups of fields, and for each, specific parameter are available to simulate land cover (e.g. Castellazzi et al., 2010), but for ecological analyses the models are not defined. However, a wide range of whole farm models have been developed to identify the best cropping plan to fit farmer objectives (Chardon et al., 2012; Pannell, 1996; Rotz et al., 1999; Rousevell et al., 2003). Some of these models do not include a spatial representation of the cropping plan (e.g. Schils et al., 2007) and cannot be used to evaluate landscape configuration. However other models include a spatial representation of cropping plans, but i) produce only one optimized crop allocation at the farm level, and ii) do not allow aggregation of several farms within a landscape (e.g. Chardon et al., 2012). The role of agronomic factors should be explored by developing a model that describes the diversity of possible crop distributions within a farming system and not only an optimal model.

The objectives of this study were to evaluate the impact of different livestock farming management systems on landscape patterns related to crops and associated biodiversity using carabid beetles (Coleoptera, Carabidae) as the model species. Carabid beetles have been extensively studied in agricultural landscapes (Koivula, 2011; Kromp, 1999; Rainio and Niemelä, 2003) and they are known to respond to the effects of landscape composition or configuration related to semi-natural habitats (Billeter et al., 2008; Duflot et al., 2015; Puech et al., 2014) or land-use diversity (Ekroos et al., 2010; Maisonhaute et al., 2010). The following hypotheses were tested: i) the adoption of different livestock farming systems generated changes in landscape patterns observed in relative amounts of spring and winter crops and crop connectivity; ii) the observed changes were modulated by the spatial characteristics of farm fields; and iii) changes influenced carabid beetle species using cropped habitats, but not on species using semi-natural habitats. Our hypotheses were tested using a modeling framework, which simulated the diversity of agricultural landscapes based on crop allocation decision rules at the farm level and estimated biodiversity based on landscape configurations. We chose two different livestock farming systems as a case study — swine and dairy — in hedgerow network landscapes (“bocage” landscapes) of Brittany (France).

2. Materials and methods

Our landscape modeling framework combined plot (crop field or woody element, here hedgerow), and its landscape context (described in a circle centred on the plot, with varying radius sizes), the landscape unit level (defined here as a 500 m radius circle), the individual farm level, and the level of several farms (eight farms in total) (Figs. 1 and 2). The model combined two ecological models predicting carabid abundance at the plot level according to plot landscape context (A), a crop allocation model at farm level integrating agronomic decisions and constraints (B), and digitized maps of real landscapes including several farm territories (C) to predict and assess landscape patterns and ecological effects produced under different scenarios of farming system combinations (D and E). The combination of ecological models with farming scenario and landscape analysis simulations were conducted in APILand virtual laboratory for landscape modeling (Boussard et al., 2010). This modeling platform includes the following: i) a meta-model of landscape representation in space, time, and theme, which facilitates a non-agricultural matrix (roads, buildings, forests, and hedgerows) and farm territory combination; and ii) temporal simulation tools to combine agronomic and ecological models.

2.1. Ecological and agronomic models

2.1.1. Predictive models of carabid beetle abundances: the ‘maize’ & ‘woody’ models (A)

Statistical modeling was performed to simulate carabid beetle abundance at the plot level (crop field or woody elements) based on the characteristics of plot landscape contexts (amount, spatial connectivity, and cultivated and uncultivated habitat heterogeneity) (see Appendix A for more details). Multi-model inference (Burnham and Anderson, 2002) applying Mixed Generalized Linear Models (GLMM) was used to link existing carabid data and landscape metrics (calculated in different radius sizes) in landscape case studies in Brittany, Western France (Duflot et al., 2014, 2015, 2016). Analyses were performed for two different indicator carabid species groups, i.e. species associated with woody habitats (’woody’ model) and species associated with maize crops (’maize’ model). The final statistical models identified for the two carabid groups (best models with the lowest Akaïke’s information criterion (AICc)) were the following:

- **Maize species**: \( N_{\text{maize}} = e^{(4.98 + (6.70 \times n_{\text{Woody}}) - (7.05 \times n_{\text{CW50}}))} \)

  where \( n_{\text{maize}} \) is the abundance of maize species, \( n_{\text{CW50}} \) is the edge length between maize and winter crops in a 500 m radius and \( n_{\text{Woody}} \) is the connectivity of woody habitats in a 500 m radius.

- **Woody species**: \( N_{\text{woody}} = e^{(3.49 + (3.40 \times n_{\text{SHDI50}}) + (8.80 \times n_{\text{CW50}}) + (1.37 \times n_{\text{SHDI50}}))} \)

  where \( n_{\text{woody}} \) is the abundance of woody species, and \( n_{\text{CW50}}, n_{\text{SHDI50}} \) and \( n_{\text{SHDI50}} \) represent respectively woody habitats and grasslands.
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