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A vegetation-based indicator to assess the pollination value of field margin flora

Charles Ricou [a,b], Chloé Schneller [a,b], Bernard Amiaud [c], Sylvain Plantureux [a,b], Christian Bockstaller [a,b,*]

[a] INRA, UMR 1121, Agronomie et Environnement, BP 20507, 68021 Colmar, France
[b] Université de Lorraine, UMR 1121, Agronomie et Environnement, BP 172, 54500 Vandoeuvre, France
[c] Université de Lorraine, UMR 1137, Ecologie et Ecophysiologie Forestières, Nancy, France

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ABSTRACT

Conservation of pollinator abundance and diversity is an important issue because it contributes to maintaining a diverse community of plant species in agroecosystems. The presence of semi-natural areas favorable to pollination is a key factor for achieving this objective of sustainability. Sowing mixtures of dicotyledonous plants that are rich in pollen and nectar as flower strips along field margins is an efficient solution to attract pollinators and to support their foraging activity on arable land. The enhancement of agroecosystems requires operational methods that make it possible to assess the impact of existing and sown semi-natural areas on pollination. We developed here a new predictive indicator that can be used at the field margin and floral levels, which predicts the pollination value of floral diversity and abundance of field margins on arable land.

We based the predictive indicator on decision trees using "if-then" linguistic rules because of the lack of sufficient quantitative knowledge about the relationships between floral traits and pollination. This approach makes it possible to use quantitative and qualitative information. We associated fuzzy subsets to the decision trees and the classes of variables in order to avoid the knife-edge effect of class limits. At the species level, the indicator depends on three criteria: (i) visual attractiveness in terms of flower size, color and UV reflection; (ii) flower accessibility according to the botanical family, the symmetry and the shape of the flower; and (iii) the reward linked to pollen and nectar quantity and quality. An aggregation procedure allows us to obtain a value at the field margin level for each month as a function of the flowering period and pollination activity. Examples of calculations for honeybees, wild bees, bumblebees and hoverflies are shown.

The evaluation of the predictive quality yielded significant correlations between pollinator abundance and the indicator value. The level of correlation is satisfying for this type of indicator, which might be further improved with additional data on plant traits. Coupling this indicator with a model that assesses the impact of management on plant diversity and abundance will be a further step to help agronomists who work on the improvement of arable farming management in order to lower its negative impact on pollination.

1. Introduction

In the second half of the 20th century, radical changes in farmland due to the intensification of agriculture and the decrease in landscape heterogeneity, especially on arable farmland, led to a huge erosion of biodiversity (Robinson and Sutherland, 2002; Tscharntke et al., 2005; Flohre et al., 2011). The work of the experts of the Millennium Ecosystem Assessment (MA) highlighted the role of biodiversity in providing numerous services for human well-being (MA, 2005). In agriculture, services have been identified and classified in the following categories: supporting (e.g. nutrient cycling), regulating (e.g. pollination), provisioning (food and fiber production) and cultural (e.g. recreation) (Zhang et al., 2007). Among them, the pollination performed by pollinator insects, especially bees, plays a major role in agricultural production (Kevan, 1999). Gallai et al. (2009) reported that 84% of the species cultivated in Europe depend on pollinators. Globally, the economic value of

* Corresponding author at: INRA, UMR 1121, Agronomie et Environnement, BP 20507, 68021 Colmar, France. Tel.: +33 03 89 22 49 8; fax: +33 03 89 22 49 21.
E-mail address: christian.bockstaller@colmar.inra.fr (C. Bockstaller).

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pollination in 2005 amounted to €153 billion, or 9.5% of total agricultural production. Several groups of insect species are involved in pollination, including honeybees, wild bees, bumblebees, hoverflies, butterflies. The conservation of this pollinator diversity is important because it contributes to maintaining a diverse community of floral species in agroecosystems (Fontaine et al., 2006). Nevertheless, pollinators have been negatively affected by agricultural intensification, habitat losses and the decrease in crop diversity in Europe (Steffan-Dewenter et al., 2002; Le Féon et al., 2010).

In arable land, field margins, defined as the entire crop edge, any margin strip present and the semi-natural habitat associated with the boundary, are important refugia for flora and fauna (Marshall and Moonen, 2002). However, in many cases, they have been reduced to a 1-m-wide grass strip. The restoration of a significant level of a semi-natural land area is a key measure to enhance biodiversity on arable land (Kleijn et al., 2006; Marshall et al., 2006). For example, the most effective solution for increasing the abundance and diversity of bumblebees is to sow simple, low-cost mixtures of dicotyledons that are rich in pollen and nectar as flower strips along field margins (Pywell et al., 2011). The flora of such strips, which depends on the composition of the seed mixture and their management (e.g. cutting regime), determines the abundance and diversity of pollinators, as shown in the case of bumblebees (Carvell et al., 2007; Pywell et al., 2011).

There is general agreement that the effective implementation of solutions designed to enhance the sustainability of farming systems and biodiversity, in particular, requires operational assessment tools in the form of indicators (Bockstaller et al., 2008). Such indicators may be used to assess the level of biodiversity of farmland, to gain insight into its ecosystem health, to monitor the evolution of biodiversity in landscapes under agri-environmental schemes, and the effect of farmers' management policies on biodiversity. *Ex post* assessment of actual systems or alternatives is distinguished from *ex ante* assessment of potential and virtual systems or alternatives (Sadok et al., 2008). Regarding biodiversity, a broad array of indicators has been developed over the last decades (Bockstaller et al., 2011). Biotic indicators are based on the direct measurement of species diversity and/or abundance for one or several taxonomic groups (Clergué et al., 2005). Indirect indicators address one or several management variables such as the percentage of semi-natural area, crop diversity, and pesticide use (Billeter et al., 2008). The former, referred to as "measured indicators" (Bockstaller et al., 2008, 2011) are assumed to provide a more accurate picture of biodiversity than the latter but do not give any insight into the cause-effect relation. Their limits were extensively reviewed by Lindenmayer and Likens (2011). The predictive quality of indirect or "simple" indicators using management variables is considered to be low but is useful for providing information on management changes. Some correlations for a very broad range of landscape conditions were found between some simple indicators such as the percentage of semi-natural habitats or crop diversity, and measured species diversity within some taxa (Billeter et al., 2008; Dennis et al., 2009). Among indirect indicators, Bockstaller et al. (2008, 2011) also identified "predictive" indicators resulting from a predictive function. This can be a complex simulation or an operational model using a limited number of available data. The main advantages of this last group of indicators are: (i) their ability to link causal variables to the species abundance or diversity within a taxonomic group; and (ii) they enable *ex ante* assessment of potential systems and address "what happens if" questions.

Several authors have developed indicator-based approaches that take account of the impact of floristic composition on honeybees (Janssens et al., 2006) at the landscape level, or bumblebees at the regional level (Buttler et al., 2009), whereas others have designed an operational model that assesses the effects of crop and landscape management on bees (Jeanneret et al., 2006) or hoverflies (Sattler et al., 2010). Floristic composition was covered in a rough way at the family level by binary (0–1) scoring system by Buttler et al. (2009). Janssens et al. (2006) assessed the effect of floristic composition at the species level by a score that expresses the potential honey production per species, so that their approach cannot be extrapolated to other pollinators. This short review shows the lack of a predictive indicator at the species level to help different stakeholders, farm advisers and even farmers to gain insight into the impact of the floristic composition of semi-natural areas on pollinator groups in agroecosystems.

The goal of this article is to present and test a new trait-based approach to assess the potential of the field margins to sustain arthropods that play an important role in pollination of arable crops: honeybees, wild bees, bumblebees and hoverflies (Gallai et al., 2009). This last group is also interesting because of its role as a beneficial in pest control (Schmidt et al., 2003). Pollinators respond to a set of stimuli and rewards that characterize flowers (Decourtye et al., 2007) and forage from flowers that differ in morphology, color and odor (Cnaani et al., 2006). We based the operational model, which structures the predictive indicator, on decision trees that use "if-then" linguistic rules based on fuzzy logic (Phillis and Andriantiatsaholiniaina, 2001), because of the lack of sufficient quantitative knowledge about the relationships between floral traits and pollination (Fenster et al., 2004). This approach makes the use of quantitative and qualitative information possible (Sadok et al., 2008). Due to the use of linguistic rules, the model may be easier to understand by non-specialists than a quantitative model based on mathematic equations. Fuzzy subsets associated with the decision trees and the classes of the variables make it possible to avoid the knife-edge effect of class limits (Bockstaller et al., 2008). This article presents the structure of the indicator, calculation examples, and results of the validation by comparing indicator outputs with the abundance of pollinators observed on field margins.

2. Materials and methods

2.1. Indicator design

First, an indicator to assess the pollination value at the floral species level was designed, and an aggregation procedure was then developed to assess the pollination value at the plant community level, using species value, floral abundance and the foraging period of pollinators.

Based on the literature (e.g. Fenster et al., 2004) and experts' knowledge, the main floral criteria with an impact on pollinator visits on flowers were selected and then organized in a nested decision tree that assessed the pollination value. We added other criteria to the main criteria of Fenster et al. (2004), reward, morphology and flower color and grouped them into: (i) visual attractiveness; (ii) flower accessibility; and (iii) the floral reward linked to the nectar and pollen content of flowers. Each of these criteria was also broken down into basic criteria. Each decision tree yielded an output in the form of a "conclusion value", which was expressed on a scale between 0 (U: unfavorable) and 10 (F: favorable). We applied the formalism of fuzzy logic presented in Tixier et al. (2007) and Sattler et al. (2010). Fig. 1 illustrates the approach through a simplified example of a decision tree with two input variables (X_1, X_2). In this example, we assumed that X_1 is continuous and X_2 is discrete for the sake of genericity. Each criterion was also structured into two classes: favorable (F) and unfavorable (U), as