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Pollination service delivery for European crops: Challenges and opportunities

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ABSTRACT

Crop pollination by bees has long been recognized as an ecosystem service of huge economic value; a large number of food crops depend upon pollination. Features across landscapes that are important for pollination delivery include: nesting habitats, floral resource availability at foraging distance, and climate. The conditions for presence/absence of pollinators are therefore complex and rely upon a combination of biotic and abiotic factors. To date there has been no easily available method for landowners to determine the potential of pollination delivery across the land effectively and rapidly. In this paper we develop a method that uses freely available datasets to remotely estimate the relative provision of pollination service delivery provided by bees across Europe at a 300 m-pixel resolution. We then identify the potential pollination delivery and efficiency across Europe at country and regional level. This study illustrates an approach that obtains a first approximation for land managers to identify potential areas across landscapes to protect in order to enhance pollination service delivery.

1. Introduction

Biodiversity loss and the degradation of ecosystems and the services they provide are major concerns facing modern society. In recent years, Ecosystem Services (ES) broadly defined as "the benefits of nature to households, communities, and economies" (Millennium Ecosystem Assessment, 2003; Boyd and Banzhaf, 2007; Fisher et al., 2009) have been progressively integrated in biodiversity policies such as the EU Biodiversity Strategy to 2020. Thus, as the importance of ES is recognized, is also appreciated that there is a need to find quick and accessible methods for landowners to be able to map and value the ecosystem service provision across their landscapes (Hauck et al., 2013; Maes et al., 2013).

The importance of insect pollination as an ecosystem service is widely recognized. An estimated 10% of the total economic value of European food production (€22 billion for Europe as a whole, and €14.2 billion for the European Union in 2005) is dependent upon insect pollination (Gallai et al., 2009). The first approach to model pollination at European scale was Maes et al. (2013). More recently, other European assessments have demonstrated that pollination by wild (e.g. bumblebees) and managed bees (e.g. honey bees) is required for 12% of EU croplands and that it is essential for 3% (Schulp et al., 2014). Within this context a major concerns for farmers and land managers, therefore, is to conserve the delivery of pollination services to maintain crop production (Field et al., 2014). Specifically, bees and the nesting sites they inhabit are threatened by land-use changes, affecting in turn the service they provide (Kremen et al., 2007; Potts et al., 2010; Steffan-Dewenter et al., 2005; Vanbergen, 2013). There is indeed an explicit policy demand for better mapping ecosystem services in general and pollination services delivery in particular (Maes et al., 2013).

How to measure pollination service across landscapes is complex and research is currently being undertaken to better understand the ecology of pollinators, their relationship within landscape, and their contribution to crop yields. One approach for example has been to identify hotspots of global pollination benefit as well as countries with high vulnerability to a decline in pollination service (Lautenbach et al., 2012; Schulp et al., 2014). But, while the pollination benefit is important to quantify, what this approach does not characterize is the distribution of landscape-scale features such as availability of nesting sites and number of pollinators to understand how landscape structure, composition,

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and richness contribute to pollination delivery. Building from these and many other studies, Lonsdorf et al. (2009) proposed a framework to model pollination service including ecological components based on field data, nesting substrates, and floral resources (Lonsdorf et al., 2009). This approach was followed by a new model which aimed to quantify the pollination demand and supply and the match between both in the European Union (Schulp et al., 2014).

Despite the steps taken in recent years to model pollination services, getting information on pollination services and their spatial arrangement across landscapes is still problematic. In particular, there is still a lack of easy-to-use tools aiming towards a quick, yet effective method to determine the pollination delivery for at a local scale across landscapes. Therefore the aim of this study was to develop an approach with a simple user input and freely available spatial datasets, models and satellite imagery, to produce a mapped output on pollination delivery at a fine-grained resolution (300 m pixel resolution). Using this approach we can remotely obtain a landscape-scale map of the important features across landscape for pollination services. Such an approach can therefore provide a first approximation for land managers and farmers to identify potential regions to invest in actions to enhance pollination service delivery. This approach is also scalable, and can therefore be used at local to continental scales to support decision-making regionally and enable questions such as "what components of this landscape should we protect?".

To achieve this, our model was built on the availability of crop pollinators including both wild and managed bees from six genera (*Andrena*, *Anthophora*, *Apis*, *Bombus*, *Megachile*, *Osmia*), the location of pollination-dependent crops, and the distance from suitable foraging habitat. Based on previous studies (Bommarco et al., 2012; Greenleaf et al., 2007; Klein et al., 2007; Lautenbach et al., 2012; Polce et al., 2013; Ricketts et al., 2008; Winfree and Kremen, 2009) we made the following assumptions in building our model:

i) For the suitable land to be classified as providing pollination ecosystem services there must be pollination-dependent cropland within the pollinator maximum foraging distance (Garibaldi et al., 2011; Greenleaf et al., 2007).

ii) The closer the nesting land cover types are to the pollination dependent crops, the greater the relative provision of pollination services will be because pollinators may be expected to forage optimally (Ricketts et al., 2008).

The overall aim of this work was to develop an approach that can be used: i) as a tool for land planners to predict consequences of different land uses on pollination services in the landscape; ii) help farmers to locate crops in places where their pollination needs are most likely to be met, and iii) to optimize conservation investments for both bee biodiversity and crop productivity. This paper describes an effective method for determination of pollination service delivery at any European parcel of land with the potential to include more or improved dataset when available. In addition, we identified which of the selected bees deliver more pollination service to European crops and which are the countries that have the highest/lowest values of pollination service delivered.

2. Methods

2.1. Pollinator-dependent crops

To determine the presence of pollinator-dependent crops for all European countries we used: the EU Corine Land Cover (CLC 2006) (The European Environment Agency (EEA), 2006) with the exception for Greece where the Global Land Cover Map for 2009 were used (GlobCover 2009) (Arino et al., 2012). The CLC 2006 and GlobCover2009 land classification were resampled to 300 m pixel size resolution.

In these landcover maps there are two classes that correspond to pollination dependent groups of crops in Europe: fruit tree and berry plantation crop (crop class 16), and complex cultivation pattern crop (crop class 20) (see Appendix A in Supporting Information). We excluded non-irrigated arable land crops, permanently irrigated land crops, and olive groves from the model because often these also contains non-pollination dependent crops such as wheat (Klein et al., 2007).

2.2. Bee pollinators: their potential distribution in Europe and richness map

To develop the potential distribution of pollinators relevant to European crops we selected twelve bee species based on Klein et al. (2007) and Garibaldi et al. (2013). These include: *Andrena flavipes, Andrena labiata, Anthophora plumipes, Apis mellifera, Bombus hortorum, Bombus lapidaries, Bombus pascuorum, Bombus terrestris, Megachile rotundata, Osmia cornifrons, Osmia cornuta, Osmia rufa/bicorni.* These bee species are known to have a wide and well-known distribution and to pollinate a broad range of crop plants (Garibaldi et al., 2013; Klein et al., 2007).

We obtained the distribution data for these twelve bees by querying the Global Biodiversity Information Facility (GBIF). In total we obtained 120,429 species occurrence data points for Europe. This data was then used to build and validate distribution models using Maxent (Phillips et al., 2006). The Maxent output showed how each bee is spatially arranged across Europe.

In developing the species distribution models we used the following environmental covariates at 300 m pixel resolution: Land cover class (The European Environment Agency (EEA), 2006), elevation (Farr et al., 2007), mean annual temperature, temperature seasonality, total annual precipitation and precipitation seasonality. Climate data was obtained from Worldclim (Hijmans et al., 2005). To evaluate the model predictive performance we used the area under the curve (AUC) of the receiver operator characteristic (ROC) (Fielding and Bell, 1997). An AUC value of 0.5 indicates a random prediction (useless model), whereas the closer the value to 1, the better the predictive ability of the model (Phillips et al., 2006). All models were validated by bootstrapping and in all cases AUC of ROC was >0.9.

Finally, we generated a species richness map involving the twelve selected bees. This map is therefore depicting which parts of the landscape have the potential to provide suitable habitat for these pollinators.

2.3. Pollination success

The next step in building this model was to calculate which areas of Europe require pollination services; this required the determination of: pollination dependent crops, bee nesting habitats, and calculate crop-bee interactions.

The following methodology was carried out on all 12 pollinators:

i) For each pollinator, the land cover maps were reclassified into classes of crops which are pollinated by the species as defined by Klein et al. (2007) and into classes which are suitable nesting habitat for the pollinator and not nesting habitat for that pollinator (Michener, 2000) (see Table S4). The set of crops pollinated by each species was tabulated (see Table S3). We also tabulated the nesting habitats of each pollinator species according to CLC 2006 classes (see Table S2).

ii) The nesting habitats map for each pollinator was multiplied by the Maxent species' distribution map (Section 2.2) to identify lands containing nesting habitats from which the pollinator potentially provides services.

iii) To account for pollination success we used distance-based approach as crude metric. The advantage of using this approach is that there is strong evidence that on average, crops 1.5 km away from areas of suitable bee nesting habitats receive only 50% of the visitation rate compared to crops adjacent to such areas (Ricketts et al., 2008). This assumption follows the work of Ricketts et al. (2008) which demonstrated that bee visitation rates decline significantly and exponentially with increasing distance from nesting sites (Ricketts et al., 2008) (see Table S1). We used this decay function to estimate relative bee foraging activity