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A novel GIS-based approach to assess beekeeping suitability of Mediterranean lands

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ABSTRACT

Honeybees are critically important for the environment and to the economy. However, there are in substantial decline worldwide, leading to serious threat to the stability and yield of food crops. Beekeeping is of pivotal importance, combining the wide economical aspect of honey production and the important ecological services provided by honeybees. In this scenario, the prompt identification of beekeeping areas is strategic, since it maximised productivity and lowered the risks of colony losses. Fuzzy logic is an ideal approach for problem-solving tasks, as it is specifically designed to manage problems with a high degree of uncertainty. This research tested a novel GIS-based approach to assess beekeeping suitability of lands located in Calabria (Southern Italy), without relying to Analytic Hierarchy Process – Multiple Criteria Decision Making (AHP-MCDM), thus avoiding the constraints due to the technique and decision makers' influences. Furthermore, the data used here were completely retrieved from open access sources, highlighting that our approach is characterized by low costs and can be easily reproduced for a wide arrays of geographical contexts. Notably, the results obtained by our experiments were validated by the actual beekeeping reality. Besides beekeeping, the use of this system could not only be applied in beekeeping land suitability evaluations, but may be successfully extended to other types of land suitability evaluations.

1. Introduction

The biodiversity and populations of insect pollinators are in substantial decline worldwide (Bommarco et al., 2012; Brittain et al., 2013; Potts et al., 2010a). Recently, much attention focused on managed honeybees (*Apis mellifera* L.) losses, since their strong population decline is a serious threat to the stability and yield of food crops. Beekeeping provides key ecological roles, pollinating a wide range of crops (Klein et al., 2007; Ollerton et al., 2011; Wratten et al., 2012), with a global value of 153 billion US$ (Gallai et al., 2009). More recently, it has been estimated that insect pollinators, including honeybees, bumblebees and wild bees, contribute at least 22 billion EUR per year to the European agriculture industry (EuropeanCommission, 2016). In detail, bees ensure pollination for over 80% of crops and wild plants in Europe, providing an essential service to crops and wild plant species (EuropeanCommission, 2016; Garibaldi et al., 2011; Lautenbach et al., 2012; Potts et al., 2010b). Furthermore, honeybees also provide honey and other apiculture products such as pollen, wax for food processing, propolis and royal jelly (AAFRD, 2005; Batt and Liu, 2012; Canale et al., 2014b; Crane, 1990).

A single factor has not been identified to explain the decline of both managed and wild bees and probably multiple factors are likely to be involved (Becher et al., 2013; Palmeri et al., 2015). Honeybees have suffered severe losses particularly since 2006–2007 in the USA, when (Oldroyd, 2007) firstly described a syndrome called Colony Collapse Disorder (CCD). The decline of honeybees seems to be due to multiple causes including the occurrence of epidemiological factors affecting honeybee health, comprising disease and parasites, the degradation and fragmentation

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of habitats in intensively managed agricultural landscapes, the loss of flower rich plant communities associated with traditional landscape uses and the negative side effects of widespread use of agricultural pesticides (Cox-Foster et al., 2007; Potts et al., 2010a; Campolo et al., 2016; Rollin et al., 2016).

To overcome the pollinators' decline, several tools have been proposed, including the introduction of flower strips (Benelli et al., 2014; Benvenuti et al., 2016; Nicholls and Altieri, 2013; Petanidou and Smets, 1995; Rundlöf et al., 2014) and early blooming shrub spots (Canale et al., 2014a) within or around intensely farmed landscapes, which helps to sustain pollinator biodiversity and promotes various ecosystem services (Wratten et al., 2012). In addition, the implementation of field margins, hedges, other buffer zones and set-aside fields has been also reported as a useful tool to overcome pollinators' decline (Decourtye et al., 2010; Rollin et al., 2016). Beekeeping activity is flexible and can be performed either in agricultural and marginal areas. In the above-described scenario, the prompt identification of beekeeping areas is strategic, since it maximised productivity and lowered the risks of colony losses. Therefore, suitability analyses can be extremely helpful to plan land uses, merging a wide range of unrelated information to produce datasets where areas are ranked by their suitability to a certain activity, according to specific requirements (Malczewski, 2006).

Multi-criteria decision-making (MCDM) is a tool that can easily cope with large number of attributes and various criteria, forming a single index of evaluation (Joerin et al., 2001). In performing this kind of evaluations, Geographic Information System (GIS) are used to retrieve, transform, analyse and display data with spatial information (Burrough and McDonnell, 1998; Domingo-Santos et al., 2011; Tassinari and Torreggiani, 2006). The evaluation of environmental components can help to determine the suitability of an area to agricultural activities, coupled with the identification of existing and potential production (Corbett, 1996). Furthermore, the MCDM method is widely used to overcome GIS limitations on analysing large datasets, as well as when is necessary to assign values to factors depending on their importance (Carver, 1991; Jansen and Rietveld, 1990). The Analytical Hierarchy Process (AHP) represents a method that can link MCDM to GIS, using a set of rules determined by decision makers in order to combine and classify attribute values into suitability classes (Chen et al., 2010). This method can be applied to a wide range of decision making problems, mainly due to its aptitude to analyse heterogeneous data, or to help if it results difficult to determine the relationship between a wide set of evaluation criteria (Chen et al., 2010).

However, the AHP-MCDM approach carries some constrains that can lead to uncertainty in the results. These can be due to many factors, including the consistence of original dataset, biased data analysis procedures and selection of criteria. In particular, choosing and weighting criteria are tricky steps, because decision makers can influence the results with personal preferences, uncertainty and imprecisions (Chen et al., 2010). Furthermore, some concerns arose on data aggregation methods and about the standardization of factors used in weighted linear combination (Jiang and Eastman, 2000). To overcome these constrains, a fuzzy approach could provide a strong logic during data standardization, and fill the gap between Boolean logic and weighted linear combination, normally coupled within MCDM method (Jiang and Eastman, 2000). Indeed, fuzzy logic is ideal for complex problem-solving tasks, having an approach much more similar to human reasoning in dealing with approximate information and indecisions, and specifically designed to solve problems with a high degree of uncertainty (Kahraman et al., 2003). This approach could represent a useful tool when the suitability analysis has to be performed in a spatial context, coping with large and unrelated dataset. To our mind, a good example is the land suitability analysis to beekeeping activity.

Therefore, in this research we employed the above discussed approach to perform a land suitability analysis for beekeeping to the whole regional area of Calabria (Southern Italy). This area was selected as a study site representative of Mediterranean marginal areas (Petanidou and Smets, 1995) suffering the continuous degradation and abandon, but with a strong tradition of rural apiculture. Therefore, a tool useful to select the profitable areas could be economically helpful to beekeepers, and of strategic importance, in order to add value to these marginal areas through beekeepers' maintenance. Notably, the data used in this study was retrieved from open access repositories, freely available on the web, thus this approach could be easily reproduced in a wide arrays of agricultural contexts.

2. Materials and methods

2.1. Study area and mapping procedure

This study was performed within the administrative limits of Calabria region (Supplementary Online Material Fig. S1), which is located in Southern Italy, between 38°53′ and 30.48″ N of latitude, and 16° 35′ and 58.2″ E of longitude. The total area is approximately of 151,832 km^2, with the elevation ranging from 0 m to 2,226 m a.s.l. The mapping procedure was composed by the following steps: (*i*) the criteria selection; (*ii*) the collection of data from public repositories; (*iii*) the development of the GIS-based suitability model; (*iv*) the generation of the suitability map (*v*) the model validation. The whole procedure was reported in Fig. 1.

2.2. Data sources

Here we determined the main environmental factors that can play a crucial role in beekeeping activity. The preliminary analysis, i.e. literature search and consultation with experts, allowed us to identify five key factors influencing beekeeping activity. These criteria were chosen based on their role in the hives, honeybee biology and colony management. Moreover, each input data was selected among those retrieved freely and globally (Table 1) from local and global public repositories. This choice was made to make this approach freely and easily reproducible worldwide.

Temperature is one of the most relevant ecological factors, considered of pivotal importance, that influence the poikilothermic organisms, like insects, playing a crucial role in their biology including their development (Campolo et al., 2014; Régnière et al., 2012). The temperature map was generated from Kringing spatial interpolation of a 30 years dataset of average temperature, considering as foraging period from April to October (obtained from ARSAC – Agenzia Regionale per lo Sviluppo dell'Agricoltura Calabrese) (Supplementary Online Material Fig. S2). We considered a positive relationship between temperature and suitability to beekeeping (Régnière et al., 2012).

Roads represent a critical factor for beekeeping. Indeed, the distance of a certain area from roads influences directly its suitability for hive transportation with vehicles. The road network was updated digitizing roads under vegetation cover, using World Street Map (ESRI®) as source (Supplementary Online Material Fig. S3). Land was considered as more appropriate to beekeeping as closer to roads.

About the hydrographic network, we associated a higher value to areas close to water sources (both rivers and lakes) (Supplementary Online Material Fig. S4). In addition, altitude can influence the land cover and subsequently everything related to the honey production. To our purpose, we associated suitability values