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Indicators of ecosystem potential for pollination and honey production

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A B S T R A C T

The estimation of the value of nature in terms of benefits derived by humans is becoming increasingly popular in environmental assessments and spatial planning worldwide. In line with this approach, the value of any ecosystem can be determined on the basis of its potential (capacity), or the actual amount of goods and services delivered (flow). The aim of this work was to develop indicators of the potential of ecosystems to deliver services related specifically to bees, i.e. to pollination and honey production. A new operational definition of ecosystem potential dedicated to the evaluation of bee-related services was introduced and applied. Two ratio scales were constructed, showing the potential abundance of nesting wild bees (indicating pollination) and the availability of honey substrates (indicating honey production). The expert assessment carried out was closely linked to real regional data. Specific values were assigned to 29 types of ecosystem relevant to bees and identified in the lowland rural landscape of Central Europe. The original scales for the indicators were then classified into the 0–10 ecosystem capacity scale. A specific study area in north-eastern Poland (815 km^2) was chosen to show a possible spatial pattern for ecosystem potential in relation to the two bee-related services.

Dry grassland and early successional pine forests were assigned highest values in terms of pollination potential, as well as cropland, young swamp pine forests and dry grassland in the case of honey production. In turn, mature alder and riparian forests, together with wetlands, ranked lowest for both bee services. This study confirmed that ecosystem capacities to deliver bee services tend to contrast greatly with potentials as regards many other ecosystem services (e.g. carbon sequestration or erosion control). This obviously complicates management policies and requires that the concept of trade-offs be embraced. The proposed indicators, as combined with detailed mapping of ecosystem capacities differ from pan-European modelling in being of value to particular stakeholders, and in support of decision-making processes regarding beekeeping, farming and nature conservation.

1. Introduction

Human existence relies on a number of goods and services delivered by the natural environment. Health, energy and safety are among the most important benefits people gain from nature. In describing how much ecological processes and functions contribute to human well-being, wide use is made of the concept of ecosystem services (MEA, 2005; TEEB, 2010; Zulian et al., 2013). In line with the recently-developed Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2013), every final ecosystem service can be assigned to one of three major sections, i.e. provisioning (e.g. food and raw materials), regulating (e.g. erosion and flood control) and cultural (physical and other interactions). Most of the services are generated as a result of complex interactions among several biotic and abiotic components, with delivery only occurring when all necessary conditions are fulfilled. Like all services, ecosystem services may be analysed and quantified from the point of view of the supply and demand sides, as well as actual flow (Burkhard et al., 2014; Maes et al., 2013). This study focuses on the supply side of the ecosystem services whose final providers are bees.

1.1. Bee services

As the world's primary pollinators, bees (*Hymenoptera: Apoidea*) are a critically important functional group (Greenleaf et al., 2007). Roughly 90% of the world's plant species are pollinated by animals, and the main animal pollinators in most ecosystems are bees (Winfree, 2010). And, in addition to a crucial role played in respect of wild plants, bees are the main pollinators of agricultural crops, 75% of which benefit from animal pollination (Klein et al., 2007). Of the more than 16,000 bee species described worldwide (Michener, 2000), honey bees (*Apis mellifera*), bumblebees (*Bombus*), leaf-cutting bees (*Megachile*) and mason bees (*Osmia*) have been recognised as the most efficient pollinators of a wide variety of crops (Nogué et al., 2016). Wild bees

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are as effective pollinators as honey bees in the cases of many crops, and in fact more effective in some cases (Winfree, 2010). Unmanaged bees alone can fully pollinate crops in some agricultural contexts, and are frequent flower visitors in others (Ricketts et al., 2008), thereby contributing to the meeting of crop needs as regards pollination (Winfree, 2010). Pollination is regarded as a fundamental regulating service in most of the ES classifications, including CICES (Haines-Young and Potschin, 2013).

Apart from pollination services, managed honey bees support human wellbeing by way of several bee outputs, among which honey is the most important. Honey has a variety of positive nutritional and health effects on humans. As the only readily-available natural sweetener, it was an important food for *Homo sapiens* from the very outset (Alvarez-Suarez et al., 2010). Honey mainly comprises carbohydrates, which constitute about 95% of its dry weight. In the long human tradition it has been used not only as a nutrient but also as a medicine – various positive effects of honey consumption on human physiology and health have been proved (see Alvarez-Suarez et al., 2010 for review). All kinds of honey exhibit strong antibacterial activity. Depending on the honey source, significant antioxidant, anti-mutagenic, anti-tumour and anti-inflammatory activity is also manifested, while skin inflammation is reduced, wound healing promoted, scar size diminished and tissue regeneration stimulated (Alvarez-Suarez et al., 2010; Molan, 2001). The annual world honey production as of 2013 was an estimated 1.66 million tons (Food and Agriculture Organization of the United Nations, 2016), which is less than 1% of total sugar production (Alvarez-Suarez et al., 2010).

1.2. Ecosystem potentials for the delivery of bee services

As this study was focused on the supply side of ecosystem services, the general definition of ecosystem potential applied concerned the capacity to deliver (supply) goods and services (Burkhard et al., 2012). In this understanding, the individual ecosystem capacities to supply services are strongly linked to:

(a) natural conditions; e.g. natural land cover (vegetation foremost), hydrology, soil conditions, fauna, elevation, slope and climate,
(b) human impacts; mainly land use but also emissions, pollution, etc.

To construct indicators and then map ecosystem potential as regards bees, a more detailed definition was needed so that ranges of values and the level of uncertainty might be reduced. In consequence, the new, more operational definition introduced holds that the potential of an ecosystem to deliver pollination and honey production services is a maximum theoretical service supply in a given type of ecosystem and regional context, calculated for the environmental setting best suited for a given service (for example as regards plant species composition, soil quality, water balance, etc.). This for instance means that, in calculating the honey potential of cropland located on fertile soil, a selection needs to be made of a crop (cultivated in the region on such a soil) that has the highest honey potential – which is to say that a hectare of that crop can allow bees to produce a larger amount of honey than a hectare of any other crop. In turn, estimations of the pollination potentials of given forest types entail selection of the most desirable plant composition and nesting resources that it is possible to encounter in the given region (within the given ecosystem type) – from the point of view of bees. Taking environmental settings other than the optimal (for example the average or most often occurring) would not reflect the full potential of the given ecosystem type.

1.3. Indicating and mapping bee services

As crop pollination is recognised as the most important contribution bees make to human wellbeing (Nogué et al., 2016), most proposals in the literature as regards modelling and indication are dedicated to this service. However, given objective difficulties with the direct identification and mapping of pollination services, proxy indicators applicable to landscape-scale assessments are usually applied in estimating service supply or flow. These include references to the abundance of bees, nesting and floral resources, or yields of pollination-dependent crops (Crossman et al., 2013).

Burkhard et al. (2012) listed potential indicators of several ecosystem services. In the case of pollination, they proposed as measures the amounts of plant products, distribution of plants and availability of pollinators.

Land cover maps serve as a basis for mapping bee habitats in the indirect assessment of pollination supply on the regional or continental scales (Lautenbach et al., 2011; Lonsdorf et al., 2009; Maes et al., 2011; Nogué et al., 2016; Schulp et al., 2014). However, often semi-natural and natural land cover patches (ecosystems) are all equally valued as bee habitats (e.g. Maes et al., 2011). In other studies, edge habitats are also extracted (Lautenbach et al., 2011; Schulp et al., 2014), but the nesting and floral resources of such patches are still assumed to be equal. The latter work also accounts for green linear elements as bee habitats (Schulp et al., 2014), though their role in promoting bee populations in intensively managed agricultural landscapes seems to be overestimated (Sardiñas and Kremen, 2015).

A major advancement in the modelling of pollination supply was achieved by Lonsdorf et al. (2009), who implemented and validated the general conceptual model describing pollination delivery across an agricultural landscape elaborated by Kremen et al. (2007). Lonsdorf et al. (2009) used information on pollinator nesting resources, floral resources and foraging distances to model the relative abundance of pollinators within nesting habitats and on neighbouring farms requiring pollination services.

A further step forward came with the work of Nogué et al. (2016), who utilised distribution data on 12 bee species (relevant crop pollinators) across Europe, and combined this with a land cover map to achieve explicit incorporation of information on habitat availability and landscape structure into a pollination model. Despite the steps taken in recent years to model crop pollination (e.g. Lonsdorf et al., 2009; Maes et al., 2011; Schulp et al., 2014), obtainment of reliable spatially-explicit information on pollination potential at the level of the parcel of land remains problematic (Nogué et al., 2016).

The ecosystem potential to produce honey is evaluated far less often, though some indirect indicators used to map pollination potential (like floral resources) could be adapted for that purpose quite readily. Jarić and co-authors (2013) proposed a formula by which the melliferous potential of plant communities could be estimated, applying this subsequently in assessing selected forest and meadow ecosystems in Serbia (Jarić et al., 2013; Macukanović-Jocić and Jarić, 2016). However, their calculations of honey potential did not account for honeydew as an underpinning raw material, and for the impact of different environmental conditions in determining how varied actual production of nectar and pollen by individuals of the same plant species might be (Demianowicz et al., 1960; Szklankowska, 1973).

Szklankowska (1979, 1973), made multi-seasonal direct measurements of total nectar secretion per ha in selected temperate forest communities. Although that author only collected nectar from undergrowth and understorey plants (not trees), her valuable work offered a basis for the reliable assessment of floral resources within natural and semi-natural ecosystems.

1.4. Objectives

The objective of this work was the development of indicators of ecosystem potential relating specifically to bees. The attention was focused on two of the primary services bees deliver (i.e. “bee services”), i.e. the production of honey as a provisioning service and pollination as a regulating service. The ultimate goal was to assign ranks to types of ecosystems (in line with indicator values), with a view to relative