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Measuring the economic value of pollination services: Principles, evidence and knowledge gaps

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ABSTRACT

An increasing degree of attention is being given to the ecosystem services which insect pollinators supply, and the economic value of these services. Recent research suggests that a range of factors are contributing to a global decline in pollination services, which are often used as a "headline" ecosystem service in terms of communicating the concept of ecosystem services, and how this ties peoples' well-being to the condition of ecosystems and the biodiversity found therein. Our paper offers a conceptual framework for measuring the economic value of changes in insect pollinator populations, and then reviews what evidence exists on the empirical magnitude of these values (both market and non-market). This allows us to highlight where the largest gaps in knowledge are, where the greatest conceptual and empirical challenges remain, and where research is most needed.

1. Pollination: a headline ecosystem service?

Animal pollination, usually via insects, birds or bats, influences the reproductive success of ~87% of flowering plants world-wide (Ollerton et al., 2011). Worldwide, ~1500 crops require insect pollination (Klein et al., 2007), and ~3 to 8% of global crop production (in tonnage) depends on insect pollination (Aizen et al., 2009). In temperate regions, most animal pollination is provided by honeybees (*Apis mellifera*), bumblebees (*Bombus* spp.), solitary bees, wasps and hoverflies, while in the tropics, butterflies, moths, birds and bats become important (Klein et al., 2007). Some crops, such as oilseed rape, are effectively pollinated by a broad range of insects, while others are specialized for pollination by particular insects; for example cocoa (*Theobroma cacao*) is primarily pollinated by midges (Klein et al., 2007). A number of bee species are actively managed, most notably the honeybee. Managed bumblebees are most commonly used in enclosed production systems (glasshouses and poly-tunnels), but other managed species are predominantly used for field and orchard crops (eg apples and almonds). Globally, evidence is emerging that wild bees and other insects are more important to crop pollination than managed bees (Garibaldi et al., 2013, 2011).

Since pollination is an ecosystem service which humans depend on through its link to world food production, it has become an often-cited example of how ecosystems services are economically valuable. The economic value flows from pollinators are both market and non-market valued. Market-valued benefits from pollinators consist of the contribution they make to the growing of a range of agricultural and horticultural crops (Gallai et al., 2009). Recent estimates suggest that crop pollination by insects underpins £430 million of crop production in the UK (Smith et al., 2011), with an equivalent figure of $361 bn world-wide (Lautenbach et al., 2012). However, there is considerable doubt over the precision, reliability, usefulness and interpretation of such figures. Non-market benefits derive from the utility which people derive from seeing pollinators or simply knowing they are being conserved and the indirect values derived from the aesthetic and cultural value of the wild flowers and garden plants which require pollination to sustain them. At any point in time, the present value of the future stream of market- and non-market valued benefits from pollinators, ie the value that can be derived in future, defines the value of this natural asset within a landscape.

The ecosystem service values derived from pollinators depend to a large extent on the condition and extent of the stock of pollinators, which is part of an area's natural capital. The value of

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pollinators as a natural capital asset depends on the stream of economic benefits which pollinators provide over time. However, in many areas, the ability of this natural capital asset to supply us with benefits has been diminished, due to pollinator population declines. Vanbergen et al. (2013) list the following main pressures on the supply of pollination services. These pressures, many of which are the result of economic activities, ultimately result in economic losses to the flow of ecosystem services from the stock of pollinators:

(1) Landscape change in agricultural landscapes: wild pollinators such as certain bumblebees may be disadvantaged from the loss of food sources due to decline in the area of wild flower meadows (Osgathorpe et al., 2011). More specialised pollinators tend to be more sensitive to the types of land use change inherent in land use intensification (Winfree et al., 2009). The increasing use of monocultures has been demonstrated to benefit wild pollinator abundances (e.g. Holzschuh et al., 2013) but can cause adverse community shifts (e.g. a reduction in long tongue bumblebees; Diekötter et al. (2010)) and may draw pollinators away from wild plants (Holzschuh et al., 2013). Increased synthetic fertiliser use and livestock stocking density can also cause significant long-term shifts in floral communities, reducing available forage resources for pollinating insects (Isbell et al., 2013; Hudewenz et al., 2012). On the other hand, farmer enrolment in agri-environment schemes which provide bee-friendly habitat will reduce the negative effects of agricultural landscape change (Scheper et al., 2013).

(2) Growing use of certain pesticides: there is evidence that insecticides such as neonicotinoids have significant non-lethal effects on both wild and managed bees, leading to reductions in foraging performance, decreased navigational abilities, reduced fecundity, and increased susceptibility to disease (e.g. Whitehorn et al., 2012; Di Prisco et al., 2013; Goulson, 2013). There is also growing evidence that contact with herbicides (Cousin et al., 2013), fungicides (Pettis et al., 2012) and even certain miticides (Berry et al., 2012) can have negative effects upon honeybee colony survival.

(3) The introduction of alien species: Invasive plants can have detrimental effects on native pollinators by displacing native flowers (e.g. Sugiura et al., 2013), although in some instances invasive plants species that are highly rewarding may benefit native pollinators: an example is the spread of Himalayan Balsam in Europe (Bartomeus et al., 2010). Invasive, non-native bees can displace native species either through direct competition or via spread of non-native diseases (Goulson, 2003; Arbetman et al., 2013).

(4) Pathogens and parasites. Pollinators suffer from a range of parasites (Vanbergen et al., 2013) and a range of bacterial, viral, protozoan and fungal diseases. The large scale anthropogenic movement of managed bees (primarily honeybee colonies and commercial bumblebee nests) has been linked with increased disease loads in the surrounding landscape (Meeus et al., 2011) and the spread of non-native parasites and pathogens against which they have little resistance (Graystock et al., 2013). The best known example is the mite *Varroa destructor*, accidentally introduced to Europe and the Americas from Asia.

(5) Climate change: climate change has been linked with changes in species range (Franzen and Ockinger, 2012) and growing mis-matches between insect emergence and floral bloom (Kudo and Ida, 2013). Which bees pollinate which crops in specific regions may also change. Honey bees are less vulnerable due to their managed status and the broad range of climates they can occupy, although their activity, and therefore service delivery, may alter (Rader et al., 2013). Climate change may also facilitate the growing of new insect pollinated crops in some regions e.g. the expansion of fruits northwards, but is also likely to result in the abandonment of some crops.

In this paper, we provide an overview of why the economic valuation of pollination services is useful to policy-makers and other stakeholders. This is followed by a brief review the methods presently utilised to measuring the economic values of insect pollinators for different end uses, highlighting the shortcomings of these methods in relation to their potential end uses. We then review the empirical literature and the proposed frameworks to highlight the main gaps in the evidence base.

2. Why measure the economic value of pollination services?

The economic value of pollination, as with any ecosystem service, has a number of potential, context-specific uses. First, economic valuation of ecosystem services is a means of illustrating the value (benefits) of conserving pollination services (Costanza et al., 2014), and alerting policy makers and other stakeholders of the risks of these services diminishing, risks which they may not have previously considered (Abson and Termansen, 2010).

Secondly, once quantified economically, the market and non-market values of pollination can be included as part of cost-benefit analysis to inform policy or business decisions and land planning (Hanley and Barbier, 2009). For instance, a decision on whether to maintain the current EU ban on neonicotinoid pesticides could be informed if the economic benefits of restricting the use of such pesticides, in terms of foregone pollination services, could be compared with the economic costs of such a policy, such as declines in agricultural yields (Goulson, 2013). Similarly, the economic benefits of enhanced wild pollinator populations arising from agri-environmental measures could be compared with the costs of such schemes, in order to prioritise and rationalise public expenditures to enhance the production of public goods (Breeze et al., 2014).

Finally, valuation allows for the construction of extended or environmentally-adjusted national accounts which show the value of changes in a country's natural capital, and to track changes in the value of the ecosystem and other assets which make up this natural capital stock (Barbier, 2011). Internationally agreement is slowly emerging on the importance of registering the economic value of ecosystem service flows in national economic and environmental reporting and accounting (ONS, 2012; United Nations Environment Programme, 2012; United Nations, 2013). An environmentally-adjusted value for Net Domestic Product (a measure of national income) would ideally incorporate both market and non-market benefits which are supplied by pollinators in any year, and also include a depreciation/net investment term to capture year-on-year changes in the capital value of the asset—its ability to provide direct *and* indirect benefits over time. However, the value of benefits to crop producers in year t from pollinators would not be added to the adjusted Net Domestic Product in year t since that value would already be included in the value of agricultural production (Nordhaus, 2006), although the benefits to consumer welfare (changes in consumers surplus) could be added (e.g. Gallai et al., 2009).

3. Conceptual frameworks for measuring the economic benefits from pollinators

In this section, the ways in which stocks of pollinator populations generate economic values is explained for (i) market-valued outputs (ii) non-market values. This leads to an explanation of