

Review

Economic Measures of Pollination Services: Shortcomings and Future Directions

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Over the past 20 years, there has been growing interest in the possible economic impacts of pollination service loss and management. Although the literature area has expanded rapidly, there remains ongoing debate about the usefulness of such exercises. Reviewing the methods and findings of the current body of literature, this review highlights three major trends: (i) estimated benefits are heterogeneous, even when using the same method, due to several often-neglected factors. (ii) The current body of literature focuses heavily on the developed world, neglecting the effects on developing countries. (iii) Very few studies are suitable for informing management and policy. The review highlights the need for fully interdisciplinary work that embeds stakeholders and economic impacts into primary ecological research.

Valuing Pollination Services

The concept of ecosystems services, the **benefits** (see [Glossary](#)) received by human society from natural ecological processes, is a major catalyst for current ecological and interdisciplinary research. Quantitative measures of ecosystem service benefits are often expressed in monetary terms. Monetisation of ecosystem service benefits is alleged to support biodiversity and ecosystem service conservation by raising awareness of impacts and facilitating budget-efficient management [1]. However, critics of monetisation argue that it has produced some political impetus but seldom any observable benefits to biodiversity or sustainable land management, with most studies remaining largely illustrative [2,3]. Furthermore, many 'payments for ecosystem services' schemes, which aim to develop markets for ecosystem service provision with defined buyers and sellers, do not base their exchanges on estimates of the monetary benefits (e.g., [4]). This has resulted in substantial debate about the worth of economic valuation in current biodiversity conservation [2,5,6].

Pollination is one of the most widely studied ecosystem services globally, underpinning 78% of global flowering plant reproduction [7] and enhancing production in 75% of globally important crops [8]. As such, monetisation of this service has attracted great interest and scrutiny, particularly regarding the methods used to elicit benefit estimates and the quality of input data [9,10]. This review presents a detailed overview of trends within the methods, locations and findings of the current literature to highlight a number of shortcomings that limit the capacity of the current knowledge base to support decisions.

Trends

Pollination is a major, economically significant ecosystem service that is threatened by biodiversity losses. Economic measures of ecosystem services are thought to support better, more sustainable management strategies and are increasingly used to justify pollinator conservation.

Converting 63 available studies that economically measure pollination services into a common currency (2015 US\$), this review identifies three major shortcomings within the current literature: highly heterogeneous results, biases towards the developed world and producers, and limited adaptability for decision-making. The review proposes next steps to enhance the effectiveness and applicability of future economic studies.

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Methods for Measuring the Economic Benefits of Pollination Services

The present body of literature on the economic benefits of pollination services takes a number of approaches of varying complexity (Table 1) and often involving a number of significant assumptions (see [9, 10] for a detailed critique). Early studies used the full crop **price** of pollinated crops as a proxy for the benefits of the service itself (e.g., [11]), which unrealistically overattributes the

Table 1. Summary of Methods Used to Quantify the Economic Impacts of Pollination Services

Method	Definition	Strengths	Weaknesses
Crop price	Sum market price of insect pollinated crops	<ul style="list-style-type: none"> Minimal data requirements 	<ul style="list-style-type: none"> Does not reflect the benefits of pollination services – only the market price of the crops sold
Managed pollinator prices	Sum market price of managed pollinators hired or purchased for pollination services	<ul style="list-style-type: none"> Reflects the benefits of pollination in a manner comparable to other inputs Differences in prices can reflect varying benefits 	<ul style="list-style-type: none"> Ignores wild pollination services Many countries have small or no pollination markets Prices are influenced by market forces more than benefits
Yield analysis	Market price of output of pollinated crops versus crop without access to pollination services based on field studies	<ul style="list-style-type: none"> Directly captures benefits of pollination services Captures more precise variations in benefit between cultivars Can capture marginal benefits 	<ul style="list-style-type: none"> Only appropriate for very local scales Requires extensive planning to capture all benefits and any pollination deficit Does not account for the relative effects of other inputs or ecosystem services Only estimates producer benefits
Dependence ratios	Total market price of crop output multiplied by a crop-specific dependence ratio (metric of the proportion of yield lost without pollination)	<ul style="list-style-type: none"> Captures the varied benefits of pollination across crops Equally applicable at all scales Minimal data requirements 	<ul style="list-style-type: none"> Only estimates producer benefits Dependence ratios may overgeneralise between cultivars Does not account for the relative effects of other inputs or ecosystem services Assumes services are currently at maximum levels
Production functions	Models of the effects of pollinators and pollination services on total crop output	<ul style="list-style-type: none"> Can accurately assess the value of pollination service stocks Can be used to model the effects of pressures on services Captures the benefits of pollination relative to other inputs and ecosystem services Can be accurately extrapolated to other locations and scales 	<ul style="list-style-type: none"> Requires extensive ecological data Models can be complex Only estimates producer benefits
Replacement costs	The cost of replacing pollination services technologically or with managed pollinators	<ul style="list-style-type: none"> Not linked to crop prices Applies at all scales Does not overattribute benefits to pollination services 	<ul style="list-style-type: none"> Replacements may not be effective Assumes producer willingness and ability to pay Not linked to benefits Tied to input and labour prices
Partial equilibrium models	Estimates the welfare value of price change on available income to producers and consumers of a single crop market	<ul style="list-style-type: none"> Can assess consumer and producer benefits Captures marginal benefits Can be used to assess impacts of service loss beyond the focal region 	<ul style="list-style-type: none"> Very complex to properly estimate, especially across regions Does not account for substitution between crops or crop inputs Subject to the quality of data on pollination benefits Does not account for the relative effects of other inputs Assumes services are currently at maximum levels

Glossary

Benefits: the positive impacts of an ecosystem good or service. These benefits can be quantified (e.g., the total market price of crop production lost) or valued (e.g., the change in consumer surplus from a change in crop prices across the market) economically.

Consumer price index (CPI): an index of the price of a selection of consumer goods. The index is reviewed by national banks and statistical authorities on a regular basis, using a select time period as the starting point for the index (which is given a value of 100). The difference between the CPI of a select year and another year is used as the basis for estimating price inflations between the two years.

Consumer surplus: a theoretical measure of the disparity between the price paid by a consumer for a good or service and their maximum willingness to pay for that good or service. For example, a consumer who acquires a good for US\$5 when they have a willingness to pay US\$9 for that good will have a consumer surplus of US\$4.

Exchange rate: a metric used to convert one currency into an equivalent amount of another currency. For example, £1 buys US \$1.3. Conversion rates fluctuate daily based on a range of market forces.

Dependence ratio: dependence ratios are theoretical metrics that represent the proportion of total crop output lost in the absence of pollination services. These values can vary between crops and varieties. See [6] for a review and [7] for a detailed critique.

Economic value: the welfare impacts of an ecosystem good or service expressed in monetary terms.

Inflation: a measure of the change in prices of common goods within the consumer price index between two time periods. Values less than 1 in the later period indicate that prices have risen since the reference period, while values more than 1 indicate that prices have fallen. This is used to adjust the value of a currency between time periods to allow for greater comparison based on the relative purchase power of that currency in each period.

Natural capital: biophysical resources from the natural environment that can form part of the

Table 1. (continued)

Method	Definition	Strengths	Weaknesses
Generalised equilibrium models	Estimates the welfare value of price changes on producers and consumers both within the crop market and across other, linked markets	<ul style="list-style-type: none"> • Values benefits to producers and consumers • Captures effects across and within markets • Can be applied at any scale 	<ul style="list-style-type: none"> • Extremely complex to estimate and analyse • Many substitution effects are not yet defined • Subject to the quality of data on pollination benefits • Assumes services are currently at maximum levels
Stated preferences	Economic survey instruments designed to estimate respondent's welfare from the maintenance or improvement of nonmarket benefits such as the existence of pollinators	<ul style="list-style-type: none"> • Values nonmarket benefits, including the existence of pollinator species • Not tied to market prices or factors • Can be used to analyse public opinion 	<ul style="list-style-type: none"> • Difficult to develop in a manner easily understood by respondents, especially if they are unfamiliar with the ecosystem service being valued • Need to ensure a representative sample and accurate responses • Requires complex modelling to analyse • Expensive to test and implement • Monetary valuation is not always applicable

basis of economic activity. For example, soil, which is required for the planting of crops.

Power purchase parity: a measure of the relative purchasing power (i.e., the amount of goods and services) of a common currency (US\$) between different regions/countries.

Price: the monetary cost ascribed to a good or service traded on a market, as affected by a number of market forces including supply of the good and demand for it or competing goods or services.

Stakeholders: a specific individual or group of individuals (e.g., farmers, supermarkets, consumers).

whole market value of pollinated crops to pollination services. This was later refined by the use of crop pollination **dependence ratios**, theoretical metrics of the proportion of crop output lost in the absence of pollination services. These metrics are derived from secondary sources (expert opinion (e.g., [12]) or syntheses of published literature [13,14]) and represent the maximum benefits of pollination services to the crop species, regardless of cultivar or growing system. Other studies have estimated the benefits of pollination to specific crops using direct yield analysis of the output difference between open pollinated and pollinator-excluded samples of a crop from primary fieldwork (e.g., [15,16]). This produces more nuanced estimates of current benefits, specific to the context of the original fieldwork (see [10,15], but see [16]). Although dependence ratios and yield analysis only attribute a portion of production to pollination, they often do not account for other factors affecting crop production, which may result in an overestimate of benefits [17,18]. More complex crop production function models that estimate the contribution of pollination to crop productivity relative to other factors have been proposed as a mean to address these issues [10]. These methods can in turn be used as the basis of pollinator production function models to estimate the benefits of pollinator **natural capital** (the biophysical stocks of potential pollinators available within the surrounding landscape, for example, [19]). Other authors have approximated benefits with the replacement costs of substituting pollinators with technology [14], or the hive rental costs of paying for managed honeybee pollination services [20]. As these costs are driven by factors such as the price of labour and fuel rather than the impacts on crop production (which can be several times higher [14]), they are not considered to be measures of pollination service benefits [9].

Although broad, the aforementioned methods do not capture the **economic value** of pollination services (i.e., the impact of pollinators on producer and consumer economic welfare). Some studies have attempted to correct this using econometric partial equilibrium models to estimate the impacts of pollinator loss on consumer welfare (measured as **consumer surplus**) [21,22]. These models estimate the impact that a rise in prices, following a change in the supply of pollinated crops, will have on consumer welfare. More recently, Bauer and Wing [23] have expanded this approach using a more comprehensive general equilibrium model to examine both the capacity of producers to compensate for pollinator losses with other inputs and the effects that such losses would have on external markets, such as the agrochemical industry. Finally, stated preference survey methods can be used to elicit the economic value of nonmarket benefits from pollination services (e.g., maintaining landscape aesthetics [24]) or pollinators

themselves [25]. Although these measures have unique value and all suffer from data limitations [9,10], to date, however, the estimates produced by these methods and the impact these limitations have on decision support have not been critically compared.

Evidence

The state of the art on estimating the economic benefits of pollination services was reviewed using a keyword search ('pollination value', 'pollinators value', 'value ecosystem services', 'pollination economics', 'pollinator economics') on Web of Science and Google Scholar, followed by a review of references and cited articles. In total (Table S1 in supplemental material online), 63 studies included an estimate of the economic benefits of pollination services.

Of these studies, 13% ($n = 8$) were international in scale, covering either global or regional values. Another 67% ($n = 42$) of studies were conducted or extrapolated to either a national or subnational regional scale. The remaining 21% ($n = 13$) of studies focused on more local scales, providing estimates of benefits per hectare or per farm. Based on United Nations (UN) subregions, 63% ($n = 40$) of these national, regional, and local studies focused partially or exclusively on the Western Europe and Others Group of developed nations (Figure 1A). By contrast, in six UN subregions, the only available estimates were from international studies.

In terms of methodologies (Figure 1B), most studies (71%) used either dependence ratio methods (27 studies) or yield analysis based on field data (18 studies). Although most studies purport otherwise, only 14% ($n = 9$) of studies estimated the economic value of pollination services to crops, most of which use simplified partial equilibrium models (but see [23,26]). Only 8% ($n = 5$) of studies estimate economic benefits aside from crop pollination: [24,25,27,28] estimate the existence value of pollination services and [23] estimates the impacts of pollination service losses on noncrop markets.

To properly compare estimated economic benefits, the results of each study were converted into 2015 US\$ using average annual spot **exchange rates** from the Bank of Englandⁱ [29] and **consumer price index (CPI)** data from the United States Federal Government's Bureau of Labor and Statistics^{ii,iii} [30,31]. **Inflation** was based on the CPI for July of the year the estimate related to compared with the CPI in July 2015. If this year was not stated, then they were

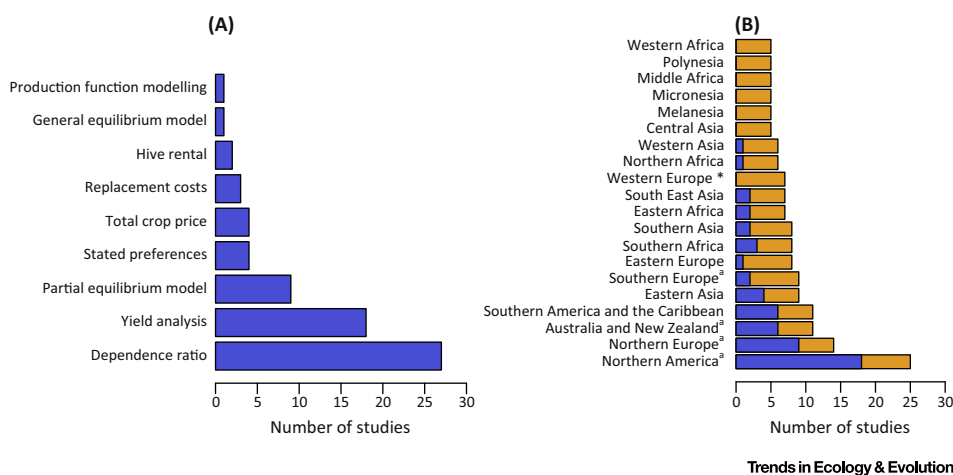


Figure 1. (A) Number of studies by method used to estimate economic benefits of pollination services. (B) Number of studies that estimate the benefits of pollination services to different United Nations geographical subregions. The blue area measures the number of studies that specifically consider this region, while the orange area measures the number of international studies that include this region. ^aRegions that form the Western Europe and Others Group.

assumed to be the year before the study was published. As total estimates will be larger in countries/regions with greater crop area, per-hectare benefits of pollination (Table 2) were calculated by dividing the total benefits estimated in each study by area of all animal-pollinated crops in each study. This area was taken from the study itself or, if this was not included, the data sources cited. This was not possible for all studies due to incomplete or inaccessible data sets. Finally, as benefits are affected by the relative market price of the crops considered [9], the per-hectare benefits to apple (Table 3), the most common crop among the studies reviewed, were

Table 2. Summary of Estimates of the Direct Economic Benefits per Hectare of Pollination sServices to Crops in 2015 US\$

Refs ^a	Region ^b	Crops ^c	Method ^d	Year ^e	2015 US\$/ha ^f
Farm/local scale					
[32]	Canada	Sweet peppers (Cubico)	Yield analysis	1992	47,784–75,190
[33]	Canada	Tomatoes	Yield analysis	2001	434–2344
[34]	Brazil	Coffee	Yield analysis	2003	2415
[35]	Costa Rica	Coffee	Yield analysis	2000–2003	173
[36]	New Zealand	NA ^g	Hive rental	2004	78–81
[37]	Kenya	Sunflower	Yield analysis	2005	2072/farm
[38]	South Africa	Apples (Granny Smith)	Yield analysis	2007/2008	18,216
[39]	UK	Raspberries	Yield analysis	2010	7641
[40]	Colombia	Coffee	Yield analysis	2011	155
[25]	Thailand	Longan	Dependence ratio	2013	3211
[41]	Canada	Blueberry	Yield analysis	2013	20,655
[41]	USA	Blueberry	Yield analysis	2013	26,541
Regional scale					
[14]	South Africa (Cape Floristic Region)	Apples, plums, apricots	Dependence ratio	2005	12,579
[14]	South Africa (Cape Floristic Region)	Apples, plums, apricots	Replacement costs	2005	2867–16,127
[42]	New Jersey, USA	Watermelons	Partial equilibrium model (CS only ^h)	2009	5393–5407
[42]	New Jersey, USA	Watermelons	Replacement costs	2009	267–312
[43]	Oregon, USA	Blueberry	Partial equilibrium model (CS only)	2011	1242–1510
National scale					
[44]	UK	16 Crops	Dependence ratio	1996	842
[45]	USA	49 Crops	Dependence ratio	1997–2009	4666–7311
[46]	Kenya (small holdings)	8 Crops	Yield analysis	2005	163
[47] ^{iv}	India	6 Vegetable crops	Dependence ratio	2007	458
[47]	India	6 Vegetable crops	Partial equilibrium model (CS only)	2007	804
[48]	UK	18 Crops	Dependence ratio	2007	1161
[49]	Ireland	Oilseed rape	Yield analysis	2009–2011	652

Table 2. (continued)

Refs ^a	Region ^b	Crops ^c	Method ^d	Year ^e	2015 US\$/ha ^f
[15]	UK	Apples (2 cultivars)	Yield analysis	2010	20,199–25,201
[50]	UK	18 Crops	Dependence ratio	2011	1321
[51]	Brazil	85 Crops	Dependence ratio	2012	1321
[52]	UK	Apples (4 cultivars)	Yield analysis	2012	14,032–24,433
Multinational scale					
[16]	European Union	Strawberries	Yield analysis	2009	14,968
[53]	Europe	All	Dependence ratio	1991–2009	75
Global scale					
[54]	Global	All	Crop value	1996	34
[23]	Global	All	Partial equilibrium model	2004	439–526
[23]	Global	All	General equilibrium model	2004	1010–1891
[22]	Global	All	Dependence ratio	2005	624
[22]	Global	All	Surplus analysis	2005	624–1721
[13]	Global	All	Dependence ratio	2009	717–1760
Average, standard deviation (SD; main methods)					US\$6976/ha (±US\$11,977)
Average, SD (dependence ratio)					US\$3588/ha (±US\$3216)
Average, SD (replacement costs)					US\$3994/ha (±US\$6872)
Average, SD (partial equilibrium model)					US\$1081/ha (±US\$388)
Average, SD (yield analysis)					US\$11,929/ha (±US\$16,522)

^aThe cited reference in which the original value was found.

^bThe region over which the estimates of benefit were conducted.

^cThe crops that were assessed for value with 'All' denoting all possible insect-pollinated crops in the region for which data were available (total number unreported).

^dMethod used to estimate benefit (Table 1).

^eThe year the estimate relates to, usually based on what year the data relate to.

^fThe per hectare monetary estimate of the study inflated (and in many cases converted) to 2015 US\$ as of July 2015.

^gDenotes studies where the method does not apply to a specific crop.

^hOnly values of pollination services to consumers.

calculated in the same way. For both tables, the mean and standard deviation of estimated benefits were calculated for each method used by three or more studies.

From this review, three notable shortcomings within the literature are apparent: first, despite a few methods dominating the literature, estimates remain heterogeneous, even for the same crop in the same region. Second, present literature is biased toward highly developed nations and international market economies with little attention in many regions and particularly developing nations. Finally, examining the literature more deeply, only a small number of studies are suitable to apply to decision-making.

Table 3. Summary of the Estimates of the Economic Value of Pollination Service to Apple in 2015 \$USD per Hectare

Refs ^a	Region ^b	Crops ^c	Method ^d	Year ^e	2015 US\$/ha ^f
Farm/local scale					
[38]	South Africa	Apples (Granny Smith)	Yield analysis	2007/08	18,216
Regional scale					
[14]	South Africa (Cape Floristic Region)	Apples	Dependence ratio	2005	12,137
[14]	South Africa (Cape Floristic Region)	Apples	Replacement costs	2005	791–1634
National scale					
[55]	USA	Apples	Dependence ratio	1996–1998	10,654
[56]	Australia	Apples	Dependence ratio	1999–2003	15,229
[45]	USA	Apples	Dependence ratio	2002	15,639
[57]	USA	Apples	Dependence ratio	2003	13,078
[58]	Poland	Apples	Dependence ratio	2004	1566
[45]	USA	Apples	Dependence ratio	2007	21,774
[48]	UK	Dessert apples	Dependence ratio	2007	20,730
[59]	China	Apples	Dependence ratio	2008	10,399
[15]	UK	Apples (Cox and Gala)	Yield analysis	2010	20,199–25,201
[45]	USA	Apples	Dependence ratio	2010	17,365
[50]	UK	Dessert apples	Dependence ratio	2011	18,902
[51]	Brazil	Apples	Dependence ratio	2012	7715
[52]	UK	Apples (4 varieties)	Yield analysis	2012	14,032–24,433
Multinational scale					
[60]	Himalayan region	Apples	Partial equilibrium model (CS only) ^g	2008/09	3975
[53]	EU	Apples	Dependence ratio	1991–2009	8016
Global scale					
[22]	Global	Apples	Dependence ratio	2005	4961
[22]	Global	Apples	Partial equilibrium model (CS only)	2005	8012
Average, standard deviation (SD; all)					US\$15,614/ha (±US\$16,583)
Average, SD (replacement costs)					US\$1212/ha (±US\$596)
Average, SD (dependence ratio)					US\$16,988/ha (±US\$20,631)
Average, SD (yield analysis)					US\$20,866/ha (±US\$3958)
Average, SD (partial equilibrium model)					US\$5630/ha (±US\$2144)

^aThe cited reference in which the original value was found.

^bThe region over which the estimates of benefit were conducted.

^cThe crops that were assessed for value with 'All' denoting all possible insect-pollinated crops in the region for which data were available.

^dMethod used to estimate benefit (Table 1).

^eThe year the estimate relates to, usually based on what year the data relate to.

^fThe monetary estimate of the study inflated (and in many cases converted) to 2015 US\$ as of July 2015. Average estimates include both the highest and lowest estimates for a study.

^gOnly values of pollination services to consumers.

Heterogeneity of Outcomes

Ideally, the economic impacts of pollination services should be estimated in a consistent, manner that facilitates comparison of status and trends across space, time, and **stakeholders**. As most estimates are closely tied to crop prices and producer costs, some variation is to be expected, however converting estimates into a common currency (2015 US\$) illustrates high heterogeneity in estimates, even between studies with common elements such as method and focal crops (Table S1 in supplemental material online). For example, of the two studies that have used the dependence ratio method to estimate the global benefits of pollination services, the benefits estimated by [22], US\$232 billion, is only as high as the lower-bound estimate from [13], US\$235 billion–US\$577 billion. Comparisons of estimates per hectare (Table 2) also show substantial variation among crops (e.g., [41,52]) and countries using the same methods. For example, despite using the same method, estimated benefits of pollination to coffee are orders of magnitude greater in Brazil (US\$2415/ha) [34] than Colombia (US\$155/ha) [40] and Costa Rica (US\$173/ha) [35]. Different methods also produce similarly large differences in estimates, with dependence ratio producing the smallest average estimates (US\$3588/ha) with low relative variation, while yield analyses produce higher estimates (US\$11,929/ha), as they mostly focus on high price crops (but see [49]), but with substantial variation.

Comparing benefits for a single crop (apples, Table 3) further highlights substantial variations between methods, with replacement costs producing substantially lower estimates (average US \$1212/ha) than other methods (average US\$4987/ha to US\$20,866/ha), while yield analyses produce the highest estimates. There are also notable variations between years (e.g., [45]) and countries (e.g., [50,58]). Methods also have substantial differences in the relative standard deviations, with the dependence ratio method having a standard deviation in excess of its mean (\pm US\$20,631; Table 3). This stems from the high degree of variation in the dependence ratios used for apples between studies, from 0.65 [22] to 1 [57], and variations in available pollinator natural capital between landscapes (e.g., [41]).

Although crop prices will naturally vary between regions and time periods, estimates are also influenced by a number of factors that are seldom considered in the literature reviewed. Foremost, the degree of pollinator dependence can have a substantial impact on estimates of economic value, particularly among dependence ratio studies [9]. This is further complicated by crop varieties often having different degrees of pollinator dependence and, in the case of certain high-value crops, different market prices [15,61]. Some studies have attempted to address these using a range of dependence ratios for each crop to present minimum and maximum measures of benefits (e.g., [13,23]). Second, estimates of economic benefits are usually tied directly to relative crop prices and production volumes, with studies considering multiple crops (e.g., [13]) often resulting in estimates being down weighted by widely grown crops with a lower market price or pollinator dependence (e.g., oilseed rape in the UK [50]).

Data availability often limits the accuracy and consistency of estimates, particularly over larger scales. For example, many studies (e.g., [13,22,23]) have utilised data from the freely available Food and Agriculture Organization database [62]. Within this database, however, there is substantially less available price data than production data, resulting in a large proportion of pollinator-dependent production either being excluded from the analysis [23] or included using price proxies [22]. This is particularly notable as price data are more likely to be absent or inconsistent in developing nations that may be more affected by pollination service losses [22,62]. Some studies use additional data to account for other factors such as quality or variety price premiums or changes in producer costs resulting from pollination-mediated yield changes [15,42].

Differences in producer costs (e.g., labour, fuel) between countries also affect the interpretation of replacement cost studies in particular and may have substantial effects on the transferability of

economic surplus models [23]. Lower labour costs, for instance, will make replacement costs lower but will have smaller effects on cost reductions, and therefore prices, when production is reduced by pollinator losses. Understanding and accounting for these drivers of values within a common framework is essential to further developing more robust, transferable estimates to larger-scale decision-making. Economic metrics, such as **power purchase parity** can facilitate such comparisons, but their use within the literature is relatively rare [13].

Geographic and Market Biases

Crop production practices and markets can vary substantially between countries and regions. As such, the benefits of pollination are likely to be very nuanced. While several global studies have suggested that the benefits of pollination services are greatest in the Mediterranean, the Middle East, and East Asia (e.g., [13,22]), to date, the more than half of published studies (63%) have only evaluated benefits to nations in the Western Europe and Others Group of developed nations (Table S1 in supplemental material online). Most of these studies focused on the UK or USA. By contrast, in seven UN regions, the benefits of pollination services have only been estimated as part of international-scale studies and there are few comprehensive, national-scale assessments of pollination service benefits in developing nations (but see [51]).

This lack of dedicated studies outside of highly developed nations is likely to result in an underestimate of the total benefits of pollination services at a local and national scale. For example, global crop databases used to estimate benefits across all regions are often lacking crops that are of little global significance but are key to local or national agriculture (e.g., Loman in Thailand [25,62]). By contrast, most of the studies into the economic value of pollinator natural capital have been conducted in developing nations. As the marginal value of natural capital increases with its scarcity within the landscape [19], such studies are likely to be particularly beneficial in developed nations where landscape homogenisation has reduced available habitat and natural capital.

Furthermore, almost all studies only examine the benefits to national crop markets, neglecting the impact of pollination services on crop trade (but see [23,40,42]). Trade has implications both for the economic value of services (by influencing prices, and thus consumer and producer welfare; [23]) and for the distribution of benefits between stakeholders. For instance, coffee is primarily produced in parts of the developing world but mainly consumed in the developed world [62]^v. Much of this trade is in turn mediated by secondary traders who buy from producers at one price while selling to consumers at another [10], however no study accounts for this cross-market effect. Understanding the distribution of benefits across these markets is particularly important to many of the world's rural poor, many of whom are highly reliant upon cash crops for their livelihoods [63]^{vi} and lack the capital to switch to different crops.

Overcoming these biases will require a focused effort to better understand the pollination service benefits in many low-to-middle income countries, as well as regions where the monetary benefits of pollination are particularly high [13]. This should be linked with focused ecological-economic research into the differing benefits of pollination services between cropping systems to identify how pollination can play a role in sustainable intensification [64].

Limited Decision-Making Tools

Ecosystem services are widely incorporated into policy and decision-making [65]. Projects including ecosystem services should be highly relevant to the stakeholders and incorporate a wide range of viewpoints (legitimacy), including economic and social impacts, to maximise their uptake [66]. Economic measures can be used in a number of ways (adapted from [67,68]^{vii}): (i) illustrating the benefits of services; (ii) measure the status and trends of pollinator natural capital (e.g., natural capital accounting); (iii) comparing trade-offs from policy and decision-making

actions (cost–benefit analysis); (iv) identifying opportunities for sustainable management (cost–efficiency analysis); and (v) designing instruments (e.g., agri-environment schemes). In common with the wider literature [69,70]^{viii}, this review indicates that most studies on the economic benefits of pollination services focus on illustrating impacts by presenting total values, without wider applicability (but see Box 1). Although these impacts can justify conservation policy and actions [69], often biodiversity and food security arguments alone are sufficient to drive large-scale action (e.g., the European Union's restriction on neonicotinoid insecticides [71]^{ix}).

To date, the few studies that have economically measured the status of pollinator natural capital [19,72,73] or pollination services [15,40,74] have been very specific, localised case studies that do not indicate wider trends. Similarly, almost all larger-scale studies do not distinguish between wild and managed pollination services (but see [20,52,56]), making them unsuitable for informing targeted management. This shortcoming stems from a lack of proper pollinator and pollination service monitoring data, making it impossible to determine their status, and subsequently economic value, across larger scales [75,76]^x. A small number of studies have examined the economic costs and benefits of specific pollination service management options [77–79], but have not isolated the impacts of pollination from other possible beneficial changes. Although some studies (Table 2) estimate the localised total value of pollination services per hectare, in reality, measures that affect pollination services will cause marginal shifts rather than absolute gains or losses [78]. As such, total benefits per hectare are only suitable for estimating the impacts of adding managed pollinators to a system without wild pollinators. Furthermore, cost–benefit analyses should include the full range of impacts that a change will have on productivity; however, to date, only four studies have examined the economic benefits of pollinators beyond crop production [24,25,27,28]. Evaluations of these trade-offs and synergies are limited by a lack of information on the impacts of interventions, pressures, or other inputs. Although new research is beginning to address these knowledge gaps (e.g., [17,48,80]), the economic

Box 1. Overview of Studies That Directly Link Pollination Economics to Decision-Making

Ricketts and Lonsdorf (2013) [19]: This study uses data collected from a yield analysis study [35] to estimate the economic value of pollinator natural capital in the surrounding landscape. The projected supply of pollination services from the surrounding landscape was then projected using the InVEST model by [87]. By reattributing projected pollination service benefits to the surrounding landscape, the study values the surrounding natural capital at US\$0 (for distant habitat that is too far from plantations to provide services) to US\$923 (2015 US\$). The maps produced are useful to prioritise forest patches for conservation based on their economic benefits and assess the costs and benefits of land use changes.

Narjes and Lippert (2016) [25]: This study uses a combination of yield analysis to directly estimate the economic benefits of pollination services to longan (*Dimocarpus longan*) in northern Thailand and stated preference survey to estimate local willingness to pay for different conservation options. The findings indicate that although there is a strong willingness to pay for pollination-management measures, this is substantially lower than the scale of economic benefits to longan production, possibly due to constraints on producer income. Respondents expressed greater willingness to pay for native bee husbandry than for improving habitat quality and had a negative willingness to pay for bee-friendly pest control. This study demonstrates that the public support for pollination service management is influenced by the management strategy more than the benefits they provide.

Morandin et al. (2016) [88]: This study uses standard yield analysis methods to provide a cost–benefit analysis of hedgerows to oilseed rape production in heavily intensified agricultural areas in California, USA over several years. The findings indicate that net profits/hectare increase by 36% (US\$158/ha 2015 US\$) in the presence of hedgerows. However, the study notes that this is much smaller than the projected benefits from pest regulation services that are needed to make hedgerows economically profitable over the long term.

A number of other studies [77–79] estimate the economic benefits of changing pollinator management practices, however as none of these studies uses a 'no pollination' treatment, they do not actively demonstrate the economic benefits of changing pollination services. Other studies [15,41,73] also explore the economic costs of pollination service deficits in gala apples, blueberries and cotton, respectively, giving some measure of the potential benefits of alternative management.

implications of these shifts in marginal pollination services and the potential consequences for management have yet to be quantified. Understanding such trade-offs is particularly important in developing countries as the opportunity costs of managing for ecosystem services rather than expanding production are often greater than in developed nations [81], although the distribution of the crop within the market (see earlier discussion) may mean that it is consumers in other countries who receive the greatest benefits.

No study has yet incorporated the economic benefits of pollination services into instrument design or efficiency measures, although some studies have provided evidence of pollination deficits, indicating economically inefficient management [15,40,41,73,82]. Although policy and management decisions often have medium-to-long-term effects, the majority of studies are single-year evaluations of economic benefits (but see [13,45,53,78]) that do not indicate how these benefits are likely to change with wider crop markets. Quantifying uncertainty in input data is important to understanding how different factors may affect the impact of management over time [83], yet most studies reviewed only consider uncertainty in the dependence of pollination services (e.g., [13]). Finally, although suitable methods for developing ecosystem service management with respect to uncertainty exist (e.g., [84]), they have yet to be applied to pollination service management. Overall, the current body of literature is largely unsuitable for supporting policy and local decision-making due to its narrow focus on illustrating the sum benefits of pollination services to crops in a single year.

Concluding Remarks

Measuring the economic benefits of pollination services is a potentially useful tool for promoting positive management, particularly among stakeholders who might not otherwise engage with ecological management. Despite several uncertainties and variations, the current body of literature does fundamentally illustrate that pollination services are economically important and that their loss will have consequences for people around the world. The current body of literature remains limited by (i) data and methodological inconsistencies, (ii) an excessive focus on developed markets and (iii) continuing emphasis on illustrating benefits rather than supporting policy and decision-making (see Outstanding Questions).

Based on the findings of this review, the authors propose a series of priorities for future research: Collaborate with a broader range of stakeholders affected by pollination services and quantify the impacts of service changes to each of them specifically. This will facilitate the use of economic measures in decision-making and is likely to provide access to data beyond the limits of existing databases and insights into crop-specific market structures. Establish a standard typology of methods, including what methods to use to address which research questions, what data should be collected to account for uncertainty and make the results comparable and how to distinguish between different sources of pollination services. Presently, standardised frameworks have been developed for assessing pollination service benefits in the field [85,86]^{xi} but not on how to translate these into economic measures for yield analysis. Refocus on functional applications of economic measures. In order to better inform decisions and policy, it is imperative that future studies have clear objectives such as (i) estimating the monetary value of pollinator natural capital, (ii) exploring the economic consequences of pressures on pollinator populations and (iii) examining the monetary benefits of positive pollination service management. Ideally, these objectives should be pursued as components of novel primary ecological research to simultaneously consider both ecological and economic impacts.

Resources

ⁱ <http://www.bankofengland.co.uk/boeapps/iadb/index.asp?first=yes&SectionRequired=I&HideNums=-1&ExtralInfo=true&Travel=NlxSSx>

Outstanding Questions

What data are required for valuing pollinator natural capital? Although great emphasis has been placed on estimating the benefits of pollination services, the value of natural capital has seldom been addressed, leaving key habitat supporting pollinators vulnerable to other economic activities. What ecological information is required to understand the relationship between habitats, landscapes and pollination services? What spatial data are required to accurately project this? And economically, what information, such as crop rotation or price discounting, is required under different contexts?

How are the economic benefits of pollination services distributed within the supply chain? The benefits of pollination services are unevenly distributed throughout the supply chain, however assessing the benefits to different groups is likely to require different data and methodologies. Given this, what information is required to properly understand the distribution of benefits from pollination services across a supply chain? How does this vary between crops and crop productive regions?

- ⁱⁱ <http://www.bls.gov/cpi/cpid1601.pdf>
- ⁱⁱⁱ <http://www.bls.gov/news.release/pdf/cpi.pdf>
- ^{iv} <http://precedings.nature.com/documents/6044/version/1>
- ^v <http://faostat3.fao.org/home/E>
- ^{vi} <http://data.worldbank.org/topic/agriculture-and-rural-development>
- ^{vii} <http://www.cifor.org/library/6051/increasing-the-policy-impact-of-ecosystem-service-assessments-and-valuations-insights-from-practice/>
- ^{viii} https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/409431/pb14221-national-pollinators-strategy.pdf
- ^{ix} <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:139:0012:0026:EN:PDF>
- ^x http://randd.defra.gov.uk/Document.aspx?Document=13755_WC1101Finalreport.pdf
- ^{xi} <http://www.fao.org/3/a-i1929e.pdf>

Supplemental Information

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References

- Costanza, R. *et al.* (2014) Changes in the global value of ecosystem services. *Glob. Environ. Change* 26, 152–158
- Silvertown, J. (2015) Have ecosystem services been oversold? *Trends Ecol. Evol.* 30, 641–648
- Spangenberg, J.H. and Settele, J. (2010) Precisely incorrect? Monetising the value of ecosystem services. *Ecol. Complex.* 7, 327–337
- Martin-Ortega, J. *et al.* (2013) Payments for water ecosystem services in Latin America: a literature review and conceptual model. *Ecosyst. Serv.* 6, 122–132
- Farley, J. (2012) Ecosystem services: the economics debate. *Ecosyst. Serv.* 1, 40–49
- Kosoy, N. and Corbera, E. (2010) Payments for ecosystem services as commodity fetishism. *Ecol. Econ.* 68, 1228–1236
- Ollerton, J. *et al.* (2011) How many flowering plants are pollinated by animals? *Oikos* 120, 321–326
- Klein, A.M. *et al.* (2007) Importance of pollinators in changing landscapes for world crops. *Proc. Biol. Sci.* 274, 303–313
- Melathopoulos, A.P. *et al.* (2015) Where is the value in valuing pollination services to agriculture? *Ecol. Econ.* 109, 59–70
- Hanley, N. *et al.* (2015) Measuring the economic value of pollination services: principles, evidence and knowledge gaps. *Ecosyst. Serv.* 14, 124–132
- Metcalf, C.L. and Flint, W. (1962) *Destructive and Useful Insects*, McGraw-Hill
- Robinson, W. *et al.* (1989) The value of honey bees as pollinators of US crops. *Am. Bee J.* 129, 411–423
- Lautenbach, S. *et al.* (2012) Spatial and temporal trends of global pollination benefit. *PLoS ONE* 7, e35954
- Allsopp, M.H. *et al.* (2008) Valuing insect pollination services with cost of replacement. *PLoS ONE* 3, e3128
- Garratt, M.P. *et al.* (2014) Avoiding a bad apple: Insect pollination enhances fruit quality and economic value. *Agric. Ecosyst. Environ.* 184, 34–40
- Klatt, B.J. *et al.* (2014) Bee pollination improves crop quality, shelf life and commercial value. *Proc. Biol. Sci.* 281, 20132440
- Melathopoulos, A.P. *et al.* (2014) Contextualising pollination benefits: effect of insecticide and fungicide use on fruit set and weight from bee pollination in lowbush blueberry. *Ann. Appl. Biol.* 165, 987–994
- Marini, L. *et al.* (2015) Crop management modifies the benefits of insect pollination in oilseed rape. *Agric. Ecosyst. Environ.* 207, 61–66
- Ricketts, T.H. and Lonsdorf, E. (2013) Mapping the margin: comparing marginal values of tropical forest remnants for pollination services. *Ecol. Appl.* 23, 1113–1123
- Rucker, R.R. *et al.* (2012) Honey bee pollination markets and the internalisation of reciprocal benefits. *Am. J. Agric. Econ.* 94, 956–977
- Southwick, E.E. and Southwick, L. (1992) Estimating the economic value of honey bees (Hymenoptera: Apidae) and agricultural pollinators in the United States. *J. Econ. Entomol.* 85, 622–633
- Gallai, N. *et al.* (2009) Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecol. Econ.* 68, 810–821
- Bauer, D.M. and Wing, I.S. (2016) The macroeconomic cost of catastrophic pollinator declines. *Ecol. Econ.* 126, 1–13
- Breeze, T.D. *et al.* (2015) A stated preference valuation of UK pollination services. *Ecol. Econ.* 111, 76–85
- Narjes, M.E. and Lippert, C. (2016) Longan fruit farmers' demand for policies aimed at conserving native pollinating bees in Northern Thailand. *Ecosyst. Serv.* 18, 58–67
- Gordon, J. and Davis, L. (2003) Valuing honeybee pollination. In *Rural Industries Research and Development Corporation Paper 03/077*. Rural Industries Research and Development Corporation
- Diffendorfer, J.E. *et al.* (2014) National valuation of monarch butterflies indicates an untapped potential for incentive-based conservation. *Conserv. Lett.* 7, 253–262
- Mwebaze, P. *et al.* (2010) Quantifying the value of ecosystem services: a case study of honeybee pollination in the UK. In *Contributed Paper for the 12th Annual BIOECON Conference*. Fondazione Eni Enrico Mattei
- Bank of England (2016) *Spot Annual Exchange Rates*, Bank of England
- Bureau of Labor and Statistics (2015) *CPI Detailed Report Data for January 2015*, Bureau of Labor and Statistics
- Bureau of Labor and Statistics (2015) *Consumer Price Index – May 2015*, Bureau of Labor and Statistics
- Shipp, L.H. *et al.* (1994) Effectiveness of the bumblebee, *Bombus impatiens* Cr. (Hymenoptera: Apidae), as a pollinator of greenhouse sweet pepper. *Sci. Hortic. (Amsterdam)* 57, 29–39
- Whittington, R. *et al.* (2004) Plant-species identity of pollen collected by bumblebees placed in greenhouses for tomato pollination. *Can. J. Plant Sci.* 84, 599–602
- De Marco, P. and Coelho, F.M. (2004) Services performed by the ecosystem: forest remnants influence agricultural culture's pollination and production. *Biodivers. Conserv.* 13, 1245–1255
- Ricketts, T.H. *et al.* (2004) Economic value of tropical forest to coffee production. *Proc. Natl. Acad. Sci. U.S.A.* 101, 12579–12582
- Sandhu, H.S. *et al.* (2008) The future of farming: the value of ecosystem services in conventional and organic arable land. An experimental approach. *Ecol. Econ.* 64, 835–848
- Nderitu, J. *et al.* (2008) Diversity of sunflower pollinators and their effect on seed yield in Makueni District, Eastern Kenya. *Span. J. Agric. Res.* 6, 271–278
- Mouton, M. (2011) *Significance of direct and indirect pollination ecosystem services to the apple industry in the Western Cape of South Africa*, MSc Thesis, University of Stellenbosch

39. Lye, G.C. *et al.* (2011) Impacts of the use of nonnative commercial bumble bees for pollinator supplementation in raspberry. *J. Econ. Entomol.* 104, 107–114
40. Bravo-Monroy, L. *et al.* (2015) Ecological and social drivers of coffee pollination in Santander, Colombia. *Agric. Ecosyst. Environ.* 211, 145–154
41. Gibbs, J. *et al.* (2016) Contrasting pollinators and pollination in native and non-native regions of highbush blueberry production. *PLoS ONE* 11, e0158937
42. Wintfree, R. *et al.* (2011) Valuing pollination services to agriculture. *Ecol. Econ.* 71, 80–88
43. Ritter, D.J. (2013) *The economic value of native pollinators in regard to Oregon blueberry production*, MSc Thesis, Oregon State University
44. Carreck, N. and Williams, I. (1998) The economic value of bees in the UK. *Bee World* 79, 115–123
45. Calderone, N.W. (2012) Insect pollinated crops, insect pollinators and US agriculture: trend analysis of aggregate data for the period 1992–2009. *PLoS ONE* 7, e37235
46. Kasina, J.M. *et al.* (2009) Economic benefit of crop pollination by bees: a case of Kakamega small-holder farming in western Kenya. *J. Econ. Entomol.* 102, 467–473
47. Basu, P. *et al.* (2011) A decline in pollinator dependent vegetable crop productivity in India indicates pollination limitation and consequent agro-economic crises. In *Nature Precedings*.
48. Smith, P. *et al.* (2011) Chapter 14: Regulating services. In *UK National Ecosystem Assessment Technical Report*. United Nations Environment Programme's World Conservation Monitoring Centre
49. Stanley, D.A. *et al.* (2013) Pollinators and pollination of oilseed rape crops (*Brassica napus* L.) in Ireland: ecological and economic incentives for pollinator conservation. *J. Insect Conserv.* 17, 1181–1189
50. Vanbergen, A. *et al.* (2014) *Status and Value of Pollinators and Pollination Services – A Report to the Department of Environment Fisheries and Rural Affairs (DEFRA)*, DEFRA, London
51. Giannini, T. *et al.* (2015) The dependence of crops for pollinators and the economic value of pollination in Brazil. *J. Econ. Entomol.* 108, 849–857
52. Garratt, M.P. *et al.* (2016) Apple pollination: demand depends on cultivar and supply depends on pollinator identity. *PLoS ONE* 11, e0153889
53. Leonhardt, S.D. *et al.* (2013) Economic gain, stability of pollination and bee diversity decrease from southern to northern Europe. *Basic Appl. Ecol.* 14, 461–471
54. Costanza, R. *et al.* (1997) The value of the world's ecosystem services and natural capital. *Nature* 387, 253–260
55. Morse, R.A. and Calderone, N.W. (2000) *The value of honeybees as pollinators of US crops in 2000*, Cornell University
56. Cook, D.C. *et al.* (2007) Predicting the economic impact of an invasive species on an ecosystem service. *Ecol. Appl.* 17, 1832–1840
57. Losey, J.E. and Vaughn, M. (2006) The economic value of ecological services provided by insects. *Bioscience* 56, 311–323
58. Zych, M. and Jakubiec, A. (2006) How much is a bee worth? Economic aspects of pollination of selected crops in Poland. *Acta Agrobot.* 59, 298–299
59. An, J.D. and Chen, W.F. (2011) Economic value of insect pollination for fruits and vegetables in China. *Acta Entomol. Sin.* 54, 443–450
60. Partap, U. *et al.* (2012) *Value of insect pollinators to Himalayan agricultural economies*, International Centre for Integrated Mountain Development (ICIMOD)
61. Hudewenz, A. *et al.* (2013) Cross-pollination benefits differ among oilseed rape varieties. *J. Agric. Sci.* 152, 770–778
62. FAOSTAT (2016) *FAO Global Crop Statistics*, FAOSTAT
63. The World Bank (2015) *Agriculture and Rural Development*, The World Bank
64. Bommarco *et al.* (2012) Ecological intensification: harnessing ecosystem services for food security. *Trends Ecol. Evol.* 28, 230–238
65. Fisher, J. and Brown, K.A. (2014) Ecosystem services concepts and approaches in conservation: just a rhetorical tool? *Ecol. Econ.* 108, 257–265
66. Posner, S.M. *et al.* (2016) Policy impacts of ecosystem services knowledge. *Proc. Natl. Acad. Sci. U.S.A.* 113, 1760–1765
67. Berghöfer, A. *et al.* (2016) *Increasing the policy impact of ecosystem service assessments and valuations*, CIFOR
68. Laurans, Y. *et al.* (2013) Use of ecosystem services economic valuation for decision making: questioning a literature blindspot. *J. Environ. Manage.* 119, 208–219
69. Martinez-Hermes, M.J. *et al.* (2015) Making decisions for managing ecosystem services. *Biol. Conserv.* 184, 229–238
70. DEFRA (2014) *The National Pollinator Strategy: for bees and other pollinators in England*, DEFRA
71. European Commission (2013) *Regulation 485/2013*.
72. Priess, J.A. *et al.* (2007) Linking deforestation scenarios to pollination services and economic returns in coffee agroforestry systems. *Ecol. Appl.* 17, 407–417
73. Olschewski, R. *et al.* (2006) Economic valuation of pollination services comparing coffee landscapes in Ecuador and Indonesia. *Ecol. Soc.* 11, 7–12
74. Cusser, S. *et al.* (2016) Natural land cover drives pollinator abundance and richness, leading to reductions in pollen limitation in cotton agroecosystems. *Agric. Ecosyst. Environ.* 226, 33–42
75. Carvell, C. *et al.* (2016) *Design and testing of a national pollinator and pollination monitoring framework: a report to the Department for Environment, Food and Rural Affairs (Defra)*, Scottish Government and Welsh Government
76. Lebuhn, G. *et al.* (2013) Detecting insect pollinator declines on regional and global scales. *Conserv. Biol.* 27, 113–120
77. Cunningham, S. and Le Feuvre (2013) Significant yield benefits from honeybee pollination of faba bean (*Vicia faba*) assessed at field scale. *Field Crops Res.* 149, 269–275
78. Blaauw, B.R. and Isaacs, R. (2014) Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependent crop. *J. Appl. Ecol.* 51, 890–898
79. Pywell, R.F. *et al.* (2015) Wildlife-friendly farming increases crop yield: evidence for ecological intensification. *Proc. Biol. Sci.* 282, 20151740
80. Klein, A.M. *et al.* (2015) Interacting effects of pollination, water and nutrients on fruit tree performance. *Plant Biol.* 17, 201–208
81. Turner, R.K. *et al.* (2003) Valuing nature: lessons learned and future research directions. *Ecol. Econ.* 46, 493–501
82. Garibaldi, L. *et al.* (2016) Mutually beneficial pollinator diversity and crop yield outcomes in small and large farms. *Science* 351, 388–391
83. Admiraal, J.F. *et al.* (2013) More than total economic value: how to combine economic valuation of biodiversity with ecological resilience. *Ecol. Econ.* 98, 115–122
84. Cong, R-G. *et al.* (2014) Managing soil natural capital: an effective strategy for mitigating future agricultural risks? *Agric. Syst.* 129, 30–39
85. Vaissière, B.E. *et al.* (2011) *Protocol to Detect and Assess Pollination Deficits in Crops: A Handbook for Its Use*, FAO
86. Delaplane, K.S. *et al.* (2013) Standard methods for pollination research with *Apis mellifera*. *J. Apic. Res.* 52, 1–28
87. Lonsdorf *et al.* (2009) Modelling pollination services across agricultural landscapes. *Ann. Bot.* 103, 1589–1600
88. Morandin, L. *et al.* (2016) Pest control and pollination cost–benefit analysis of hedgerow restoration in a simplified agricultural landscape. *J. Econ. Entomol.* Published online May 11, 2016. <http://dx.doi.org/10.1093/jeetow086>