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Accounting for the value of pollination services

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Outline:

- Defining the asset and the value flows
- Why account for the value of pollination services?
- How, ideally, would we measure changes in the value of the asset over time?
- What do we actually know about these values? (for the UK)
- What are the threats to the condition or value of this asset? Are there important threshold effects to consider?
- Gaps in knowledge

1.Defining the asset and the value flows

The asset considered in this paper is the UK population of insect pollinators.

Pollination via wind, gravity or animals is essential for reproduction in most flowering plants. Animal pollination, usually via birds, bats or insects, enhances the reproductive success of ~80% of flowering plants. Within the UK, most pollination is done by honeybees, bumblebees, solitary bees and hoverflies. Honeybees (*Apis mellifera)* are often referred to as "managed bees", since most are owned and managed by bee keepers. Managed bumblebees, such as the buff-tailed bumblebee (*Bombus terrestris*) and red mason bee (*Osmia bicornis*) are also increasingly utilised to provide pollination services in enclosed or partially enclosed production systems. Most bumblebees however, and all solitary bees and hoverflies, are referred to below as "wild bees", since they are not owned by anyone. Globally, evidence is emerging that wild bees and other insects are more important to crop pollination than managed bees (Garibaldi et al, 2013).

Since wild bees and managed honeybee colonies persist over time and thus provide a flow of services over time[1], both groups can be thought of as assets. As noted above, wild bees are assets not owned by anyone. Honeybees, in contrast, are owned and managed similarly to other assets. Added together, managed honeybees and wild bees constitute a UK national asset. This asset can depreciate over time if the aggregate values of the services falls (eg due to a decline in pollinators, or a decline in the value of their services), and can be invested in, for example by planting wild flower strips to boost populations of wild bees (Pywell et al, 2011), or by bee keepers establishing more hives.

The value flows from pollinators are both market and non-market, as explained in detail in section 3. Market-valued benefits from pollinators in the UK consist of the contribution they make to the growing of a range of agricultural crops, including top fruit, soft fruit, tomatoes, field beans and, most importantly, oil seed rape. There is also a market value attached to honey production from managed hives. Non-market benefits derive from the utility which people get from seeing bumblebees or simply knowing they are being conserved (willingness to pay for this is signalled by people paying to join the Bumblebee Conservation Trust: www.bumblebeeconservation.org). Non-market benefits are also derived indirectly from pollinators in terms of the wild flowers and garden plants which they pollinate. At any point in time, the present value of the future stream of market- and non-market valued benefits from pollinators defines the value of the asset.

2.Why account for the value of pollination services?

There are three reasons why one would want to try and add up the value of services supplied by UK pollinators.

The first relates to the construction of extended or environmentally-adjusted national accounts. As Barbier (2012) shows, an environmentally-adjusted value for Net Domestic Product would add in the

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[1] Honey bee colonies can persist for several years. In contrast, queen bumblebees start a new nest each year. These nests consist of up to 400 individuals. At the end of the year, all the new queens hibernate, whilst the old queens and all the males and female workers die. In the spring, the new queens emerge, and start to form new colonies.

non-market benefits which are supplied by pollinators in any year, and also include a depreciation/net investment term which showed how the capital value of the asset – its ability to provide direct *and* indirect benefits over time, in Barbier's words – changes year-on-year. The value of market-valued benefits in year *t* from pollinators would not be added to adjusted NDP in year *t* since that value would already be included in the value of agricultural production (Nordhaus, 2006).

A second reason would be if we want to construct comprehensive wealth accounts, or show how the natural capital component of comprehensive wealth is changing year-on-year due to changes in the present value of future pollination benefits. This might be done as part of an exercise to calculate Genuine Savings (comprehensive investment) for the UK, as an indicator of weak sustainability (Pearce and Atkinson, 1993; Pearce and Barbier, 2000). No Genuine Savings calculation for the UK to date has included the change in natural capital due to a change in pollination service flows[2].

A third reason would be if we wanted to include market and non-market pollination values as part of a cost-benefit analysis, perhaps to inform a policy decision. For instance, a decision on whether to maintain the ban on neonicitinoid pesticides could be informed if we knew what these values were (Goulson, 2013).

3.Ideally, how would we measure the values (benefits) we get from pollinators?

In this section, the way in which pollinator populations generate economic values is explained for (i) commercial, market-valued outputs (ii) non-market values. From a national accounting viewpoint, economic value is best thought of in terms of marginal values. That is, as a pollinator population rises or falls by one "unit" (e.g. one percentage point of a population), what is the change in benefits we receive from pollinators?

3.1Commercial values

For commercial, market-valued outputs such as agricultural crops, we know that pollination services (*PS*) are an input to production. For any crop dependent on insect pollination, we could write down the general form of a production function which relates the physical yield of a given crop, X1, to variations in the supply of pollination services *PS*:

$$Q(x1) = f\,(Y, PS, \varepsilon) \qquad (1)$$

where Q(x1) is tonnes of output per hectare, Y is a vector of inputs such as labour hours, machinery time, fertiliser and pesticides, and ε represents stochastic factors such as rainfall and temperature. Pollination Services are thus an input to production of many crops, and in many ways are treated in conceptually the same way as other inputs. There will be a separate production function for each crop (x1, x2, x3..) relevant to a farmer's choices of what to grow.

However, the supply of pollination services is different from other agricultural inputs in three important ways. First, the effects on output of a given population of pollinators are stochastic: there is some probability that each flower in the crop will be pollinated. Call this *v.* But that means there is also a non-zero probability (1-*v)* that the crop will not be pollinated. Farmers can only partially

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[2] See Greasley et al (2013) for an attempt to value changes in parts of the UK's natural capital over time.

control this probability. The lower the chance of a flower being pollinated, the higher the marginal value of additional pollinators (Simpson, 2013). Second, once a flower has been sufficiently pollinated, it does not benefit from any further inputs of *PS*, and crop plants can be damaged if too many flowers are pollinated whilst providing other inputs in the "no pollination" scenario can generate zero output for some crops. This is quite unlike other inputs such as fertiliser. It is wrong, therefore, to think of pollination services and other inputs as perfect substitutes for each other in production of a given crop (Bommarco et al, 2013). This contrasts with most other inputs farmers use. Third, whilst farmers have to pay for many other inputs they use (seed, fertiliser), some pollination services are provided at little or no direct cost to the farmer.

The potential supply of pollination services *PS* often depends on both the diversity and abundance of different insects (honey bees, bumble bees, hoverflies etc), labelled S1, S2 and S3. As the abundance of any of these species falls or rises, then we wish to know the marginal effects of this on the output (yield) of X1, holding all other factors constant. This quantity – the change in Q(x1) for a marginal (one-unit) change in S1 - is known as the marginal physical product of X1. Or, we can ask how the quantity of output of X1 changes as the supply of pollination services, PS, changes by one unit. This is the marginal physical product of pollination services. These marginal product values will vary across crops and possibly also across the country, due for example to variations in soil fertility or climate. They will also vary for any farmer according to how much of each input they utilise, so that the marginal products are not constants, but vary as a function of the quantity of other inputs and the quantity of output. Finally, as noted above, the marginal products are not defined with certainty, since pollination is a stochastic event.

The relationship between the overall supply of pollination services in a landscape, *PS*, and the abundance of individual pollinator species, will depend on their effectiveness as pollinators and the extent to which they either act as substitutes for each other (that is, to what extent can a 5% decline in visitation by species S1 be compensated for by a z% increase in visitation by species S2?); or as complements for each other (both S1 and S2 are required to produce the crop; or more of S2 enhances the yield given a fixed level of S1). This information on effectiveness and substitution/complementarity is contained within the empirical (functional) form of the pollination services production function, which will be crop-specific:

$$PS(x1) = f(S1, S2, S3\ldots.) \qquad (2)$$

Species abundance at any site for any point in time will depend on a range of factors, including forage and nesting resource availability.

So far we have discussed the value of pollination services in terms of yields. However, farmers' production decisions depend on expected profit, not yields. For any crop, we could define a profit function which showed how profits per hectare from growing X1 vary according to the price the farmer receives for X1 and the costs of the inputs Y (fertiliser, pesticides..) including any costs of purchasing pollination services *PS* (eg. by hiring managed bees). Profits will also depend on the marginal physical products of each input, including pollinators. Such a profit function could be defined at the level of the farm. In this case, the prices of all outputs (crops) the farmer could grow, along with the costs and marginal physical products of each input, would be relevant to determining the maximum profit he can make, and determining the combination of crops and management regime which result in this maximum.

To understand the commercial value of any pollinator species, consider an experiment where we can quantify the effect of a 10% change in the abundance of species X1 on the supply of pollination services, holding all other factors constant. Suppose this results in a 5% loss in the supply of pollination services. We then ask what change in the maximum profit each farmer can make results from this 5% decline in *PS*. If such an experiment could be repeated for a range of changes in S1 and thus in *PS* for a given crop or across a range of crops, this would trace out a function which would tell us the marginal value of pollinator species S1 in terms of market or commercial values – its value in agricultural production. Since such an experiment would be hard to conduct, such a function could be estimated econometrically, observing levels of S1 and PS, and levels of profit, and the controlling for other factors in (1) and (2) statistically. However, data to do this well does not currently exist for the UK. The partial derivative of this profit function with respect to S1 gives the marginal value of the species, which might well vary with the abundance of the species (and as should be clear from the above, with the abundance of other pollinators – other determinants of *PS* in (2)). This marginal value could exhibit great discontinuities if there are thresh-hold effects present in the system (e.g. sudden collapses in wild bee populations under a particular pressure).

Therefore, in estimating the value of a particular pollinator species in agriculture, it is important for the researcher to know the form of the pollination services supply function (2), as well as the profit and production functions facing each farmer. As a species such as S1 increases or decreases in abundance, the economic benefit or cost of this change will thus depend on:

- The extent to which other species can replace the functioning of S1 in the supply of *PS*, as in (2);
- The extent to which farmers can and do change their production methods in producing a given pollinated crop under low pollination service levels, for example by changing their use of other inputs;
- The costs to farmers of such changes, and the costs of switching to alternative crops with different pollination demands.
- Since the price of outputs (crops) and the price of inputs are part of the profit function, then the costs of a decline in pollinators will also depend on crop prices and other input costs. For example, as crop prices rise, the costs of losing pollination inputs also rise. As input prices rise, the cost of losing pollination inputs might fall, since higher input prices could imply the farmer choosing to target lower yields through less intensive cultivation systems.

An empirical estimation of the commercial value of pollination is thus quite complicated, but absolutely vital if policy-makers need a robust figure for the market-valued economic benefits of protecting pollinator populations, and thus the economic costs of declines in pollinators.

Finally, wild pollinators act as an insurance for farmers in terms of the supply of pollination services (Baumgartner, 2007). If there is an unexpected decline in commercial bee populations (due, for example, to a disease outbreak), then the presence of wild pollinators can act as substitutes for this input (Garibaldi et al, 2013). Wild pollinators thus reduce the variability of farm profits over time and farmers might opt to invest in a range of such wild pollinators – for instance, by planting wild flower margins – in a similar way in which they can opt to pay insurance premia. However, an important consideration in this case is whether the risks of commercial pollinator decline are positively or negatively correlated with the risks of wild pollinator decline.

3.2 non-market values

Insect pollinators provide benefits to society in many ways which are additional to their role in commercial farming. From an economic value viewpoint, this happens in at least two ways.

First, individuals derive pleasure from seeing pollinators and knowing they exist. Such use and non-use values are direct benefits to individuals from the presence, diversity and abundance of pollinators such as bumblebees. As presence, abundance and/or diversity increases, then utility may also increase. The monetary value of such increases in utility is given by an individual's willingness to pay for such an improvement in pollinators. For an individual *a,* we could write:

$$U_a = f(S1, S2, S3, Y, N, E) \qquad (3)$$

where Y is income, E is other environmental attributes and N is all other goods and services in the individual's choice set. The marginal, direct non-market value of a change in population S1 is thus the partial derivative of (3) with respect to S1. For honeybees, the direct utility value can occur through the pleasure that bee-keepers obtain from their hobby.

Second, individuals may care about the consequences of pollinators' actions. For example, this could be through the effects of wild pollinators on the diversity and abundance of wild flowers and trees. If people enjoy flower meadows, then they get an indirect benefit from the actions of pollinators. People who enjoy growing flowers and vegetables in their own gardens or allotments also get an indirect benefit from the actions on pollinators. If we assume that the variable E in equation (3) captures the importance of wild flowers and trees and of gardens and allotments to people, then the indirect, non-market economic value of pollinators is given by the effects of changes in a population or several populations on E. Ideally, we would want to empirically measure the partial derivative of E with respect to S multiplied by the partial derivative of U with respect to E.

The value of the stock of pollinators at any point in time depends on their contribution to (i) market-valued outputs (ii) direct contributions to utility (iii) indirect contributions to utility via effects on landscape quality and gardens. It also depends on the degree of substitutability/complementarity between different species, and between commercial and wild pollinators, since that determines how changes in individual populations translate into changes in the delivery of pollination services. The ability of the stock to provide the current service flow is likely endangered by reductions in species diversity or by declines in abundance or performance (e.g. effects of insecticides on navigation). Reductions in species diversity would result in a decline in the value of pollination services if there is imperfect substitutability between species in terms of which flowers they can pollinate (so that an increase in honeybees would not necessarily maintain all the service value if there is a decline in wild pollinators). Thresh-hold effects in the supply of pollination services due to a decline in the condition of the pollinator asset would result in large changes in the shadow price of this asset.

3.3 Can we substitute for the services of individual pollinator species?

Substitutes for crop pollination: There are substitutes available for wild pollinators in their role in crop pollination. There is a large industry in commercial bumblebees, which were developed for use in greenhouses but can be used in polythene tunnels and in open fields. There is also increasing use of *Osmia bicornis* in man-made nests which can be placed throughout orchards and fields, and globally, efforts are being made to domesticate other species. Honeybees themselves are a substitute for wild pollinators (Willmer et al, 1994). Further research and development may increase the commercial availability of non-bee pollinators such as hoverflies. A difficulty with substituting wild pollinators entirely is that such substitutions are costly, and substitution may not be perfect; one commercial species is unlikely to provide the breadth of functionality provided by a natural community (Hoehn et al. 2008). Substitutes are however, useful for increasing the abundance of pollinators in a location at a particular time, particularly if they share the functional traits of wild pollinators.

Substitutes for wild plant pollination: While honeybees do pollinate wild flowers (Tuell, Fiedler et al. 2008), and bee farmers focused on honey production will move nests to utilise wild flower resources (i.e. heather), honeybees are not able to pollinator all wild flowers both due to morphological and phonological limitations. Even if they were able to pollinate all wild plants which require insect pollination, it would require a redistribution of the honeybee stock to woodland, grassland and riparian habitats, and away from urban areas, which would be infeasible from a cost and management perspective. Wild plant pollination is therefore much more difficult to substitute and therefore more vulnerable to loss of pollinators than crop pollination**.**

4. What, actually, do we know about these values for the UK?

4.1Market values

Most studies have focused on estimating the value of pollination as an input into crop production, often using a simplified production function known as a dependence ratio (DR). DR studies estimate the proportion of yields that would be lost without pollination services, using published studies on the yield responses of different crops to pollination. Yield declines can vary from moderate (e.g. field beans; 25%) to high (e.g. apples; 85%) between crops. This approach was taken in the UKNEA (2011) for all UK crops in 2007 (see Table 1, which has been updated for 2010) and has been similarly applied in a number of other countries, such as the USA (Calderone et al, 2012) as well as globally (Gallai et al, 2009). The approach serves to highlight those crops (and thus farmers) which are especially vulnerable to pollinator declines.

Table 1. Crop dependencies on pollinators and annual value of pollination in the UK, 2010

Crop	Dependence on Pollinators (%)	Production Value (£ millions) 2010	Pollination Value (£ millions) 2010
Oilseed Rape	25	674	169
Strawberries	45	261	118
Dessert Apples	85	63	54
Raspberries	45	103	46
Cucumbers	65	53	35
Culinary Apples	85	40	34
Tomatoes	25	115	29
Runner Beans	85	17	14
Pears	65	16	10
Plums	65	13	8
Other	5-85	285	88
Total			Approx. 603

The DR approach is simple to apply, as the dependence ratios themselves can be drawn from review papers such as Klein et al (2007), but the insect pollinator dependence ratios used are often based upon studies from different countries or even continents, are not collected in a standardised manner and usually only consider changes in crop quantity, neglecting effects on quality parameters which may affect prices paid (eg for strawberries). Recent field studies have attempted to correct these faults by evaluating the benefits of pollination services to yields and quality of crops in the field and extrapolate this to a national scale. For example it has been recently estimated that insect pollination in the two main varieties of English dessert apple orchards added ~65% to per hectare profits by increasing the number of apples produced and proportion of class 1 apples; adding £36.7M nationally (Garrat et al (2013). Nonetheless, these studies still overestimate the role of pollination by not accounting for the effects of other inputs on yield. Moreover, by focussing on average (per tonne) values, they do not tell us what the marginal cost of a decline in pollinator services would be, still less about how these marginal values change over time or space. Finally, such figures do not allow farmers to respond to changes in the supply of pollination services by switching production to less-dependent (although probably less profitable) crops.

Alternatively, the value of pollination services can be equated to the costs of replacing these services artificially, reflecting the costs to producers avoided by the presence of pollinators. For example, it has been estimated that it would cost an additional ~£370-£1,400/ha to produce tree fruit such as apples and plums by hand pollination (Allsopp, 2008). Unlike DR studies, replacement cost studies do not over-attribute benefits to pollination services and can transfer work hour and materials costs between countries. However, it is unlikely that this method would be applicable for all crops as artificial pollination methods have proven ineffective on a number of crops, and are likely to be too costly for producers in developed nations where labour costs are higher. This means that farmers would switch out of crops requiring insect pollination. More importantly, the approach tries to measure the value of a benefit by using the avoided cost approach; we know that this is very unlikely to produce a figure which is close to the real value of a beneficial ecosystem service, due to issues of substitutability, joint products and the need for the least-cost alternative to be considered (Hanley and Barbier, 2009).

Finally, a recent study (Winfree et al, 2011) has attempted to marry dependency and avoided cost methods into a single assessment of the value of pollination for watermelon production in Pennsylvania. By extrapolating observed benefits of pollination services to a county scale and the estimated effects on prices at a state wide level should insect pollination collapse within that county only, the authors provide an estimate of both producer and consumer losses. However, this approach has not been applied in the UK so far, and does not produce values consistent with national accounting principles.

4.2 Non-market values

Above, we set out two ways in which pollinators could provide non-market benefits to individuals. These were (i) direct benefits, whereby people care about the population of certain pollinators in and of themselves – eg for bumblebees; (ii) indirect values, whereby pollinators contribute to the production of things which people care about – wild flower meadows, garden plants. In both cases, markets fail to register the full value of these benefits, since they have the characteristics of non-rivalness (the number of people who benefit from an increase in wild pollinators does not affect the value to any individual of this change) and non-excludability (if pollinator populations are increasing, then no-one can be excluded from benefitting from this increase even though they did not pay for it).

Economists have developed a range of methods for measuring such non-market values, which are described in numerous texts. However, for both direct and indirect values, it seems likely that only stated preference approaches would be a feasible choice of method for pollinators in the UK. Stated preferences work by asking a sample of individuals to either state whether they would be willing to pay a particular sum of money for an increase in an environmental good, or their willingness to accept compensation for a decline in this good (contingent valuation); or by asking people to make choices between different "bundles" of environmental attributes and a price (choice experiments). These responses are obtained in the context of a carefully-constructed hypothetical market for the good in question. Features of such markets which have been shown to be important are (i) that respondents feel that their responses are consequential (ii) that a non-voluntary payment mechanism be used (iii) that the environmental change in question be clearly described, and (iv) that the hypothetical market is realistic and does not encourage ethical rejection.

For direct benefits, where people care about the populations of pollinators, either contingent valuation or choice experiments could be used to estimate willingness to pay for a change in such populations (e.g. a 10% increase in bumblebee abundance over a 5 year period in Surrey). Choice experiments would enable the researcher to measure the impacts of different attributes of such a policy change on people's preferences – such as whether they prefer an increase in species diversity rather abundance, or whether they prefer policy to be targeted at endangered or common species. Either method could be used to show how the non-market direct benefits of pollinators vary across the country and across income groups.

For indirect benefits, choice experiments and contingent valuation could be used to value changes in the environmental goods which pollinators help to produce, such as wild flower meadows. However, it would be difficult to design a study in such a way that one could isolate the contribution of (wild) pollinators to the production of the environmental good which people are valuing (e.g. a 25% rise in the number of wild flower meadows in Devon). Thus, identifying this indirect, non-market value of pollinators would be a challenging exercise.

Whilst there are many studies in the literature which apply stated preference methods to estimate the value of conserving individual species and aspects of biodiversity, at present only one (un-published) study has undertaken stated preference estimates of either direct or indirect non-market pollinator benefits in the UK (Mwebaze et al, 2010). This resulted in an estimate for the existence value of protecting honeybees in the UK of £1.77bn/year. However, this study is based on a small and non-random sample of the public, whilst the question used to elicit willingness to pay means that this figure confuses the market- and non-market values of pollinators. Moreover, since the survey did not contain any statement regarding the consequentiality of responses, there was no incentive for participants to reveal their true values. Finally, it is not clear how we could use this value in a natural capital accounting exercise, since it does not relate to the marginal value of changes in populations of pollinators. The information content of this value estimate is thus rather low.

5. Threats to the condition of the asset, and the possibility of thresh-hold effects.

Focussing on major insect pollinators in the UK, Vanbergen et al (2013) list the main pressures on the future supply of pollination services as follows (our text is a summary of their text):

1. <u>Landscape change in agricultural landscapes</u>: wild pollinators such as certain bumblebees may be disadvantaged from the loss of food sources due to decline in wild flower meadows or in traditional croft-land (Oglethorpe et al, 2011). More specialised pollinators tend to be more sensitive to the types of land use change in UK agriculture landscapes which we have witnessed over the last 50 years (Kliejn and Raemakers, 2008). The increasing use of monocultures may also have adverse effects, due to the short time period during which food resources are available from a single crop (Carvell et al, 2007 but see Jauker et al, 2012). The recent expansion of oil seed rape in the UK provides a valuable forage source for many bees, but may reduce their pollination of wild plants (Holzschuh et al, 2011), and may also change the composition of wild pollinator communities over time, due to increasing competition between species (e.g. short-tongued vs long-tongued bumblebees - Diekoetter et al, 2010). On the other hand, farmer enrolment in agri-environment schemes which provide bee-friendly habitat will reduce the negative effects of agricultural landscape change. Both entry-level and higher-level Environmental Stewardship contains measures which are likely to benefit wild pollinators.

2. <u>Growing use of certain pesticides</u>: there is evidence that pesticides such as neonicotinnoids have significant non-lethal effects on bees, leading to reductions in foraging performance and queen production (eg Whitehorn et al, 2012).
3. <u>The spread of roads and urban areas</u>: loss of certain ecosystems to urban development can deprive bees of forage resources, and may mean that colonies become genetically isolated over time. On the other hand, urban gardens and parks can provide new forage and nesting areas for bees, depending on which flowers are grown, which may be better than agricultural land (Goulson, 2002). While urban areas can provide diverse resources for bees, the recent increase in honeybee densities within cities due to uptake of urban beekeeping, has increased concerns over disease spread and competition between honeybees and wild bees in these areas.
4. <u>The introduction of alien species:</u> Bringing new plant species into a country may actually benefit pollinators since it can provide new food resources. An example for the UK is the spread of Himalayan Balsam. However, the introduction of alien bee species by commercial beekeepers or farmers can impose disease risks on domestic pollinators, as with the Varroa mite.
5. <u>Pathogens and parasites.</u> Diseases such as European and American foulbrood can affect honey bee colonies, along with vector-borne diseases such as Deformed Wing Virus which is associated with the Varroa mite. Colony Collapse Disorder has also been a problem in the USA, but not in the UK.
6. <u>Climate change:</u> climate change may well shift species, reduce the abundance of some specialist species, and may adversely affect the ability of bumblebee queens to establish new nests. Which bees pollinate which crops in specific regions may also change. Honey bees are less vulnerable due to their managed status. Climate change may also facilitate the growing of new insect pollinated crops in the UK or the expansion of fruits northwards.
7. <u>Interactions between the above.</u> The synergistic effects of these six factors operating concurrently will be harder to predict, but may produce effects that are larger or smaller than the sum of individual effects.

Ellis et al (2013) consider whether the current ability of UK pollinators to supply pollination services is being maintained. Although honeybee numbers are increasing, this may not lead to increased pollination services, as the increase in number of colonies is made up of those kept by amateur beekeepers, mainly in suburban areas. Also some crops and many wildflowers are not well pollinated by honeybees. However the condition of honeybees is well monitored and new policies in place will further safeguard honeybees. Wild bee diversity has declined and insect pollinated wild plant species richness continues to decline in some habitats. Monitoring efforts have so far detected losses of rare species, but as there are no systematic schemes for monitoring the abundance of common species, trends are unclear. Pollination services to wild plants are at risk, particularly for specialised plant species, as the diversity of these have declined in parallel with pollinators with narrower niche breadth. Whether the asset as a whole is able to support crop pollination depends on the specific requirements of crops, and on farmers choices in the future of what to grow.

Ellis et al (2013) then consider the likely existence of threshold effects in pollinator populations, and the robustness of such populations to change. A diverse mix of wild pollinators and honeybees will reduce the probability of collapse of pollinator services. That being said, a poorly managed epidemic affecting either honeybees or *Bombus* spp would be likely to cause significant reductions in services available that year. Honeybees are the most vulnerable to such a shock as diseases can spread quickly between colonies. Crops or wildflowers which depend on long-tongued species of bumblebees are also somewhat vulnerable, as there are fewer species to replace this service if lost. As noted above, there is some evidence that mass-flowering crops such as oil seed rape support short-tongued species at the expense of long-tongued bumblebees (Diekotter et al, 2010). The integrity of the asset could decline in a non-linear way if there is a positive feedback between wild flower diversity loss and pollinator diversity.

Finally, they look at whether losses in the asset could be reversed. Most pollinator species in the UK complete one or more generations per year, and can be expected to undergo stochastic fluctuations due to weather or other perturbations. While the short generation time enables wild bee numbers to bounce back after a poor year, many "bad" years in succession or a chronic threat to bees will ultimately have an impact on populations which will not be recoverable until the threat is removed. Should such a threat cause a population to go locally extinct, the area is likely to be recolonised once the environment is conducive again. However if the threat is widespread then local recolonisation may not be an option. It is extremely difficult, though not impossible, to reintroduce pollinator species which become nationally extinct. Attempts are being made to reintroduce *Bombus subterraneous* to the UK with limited success so far. Even after a successful reintroduction it would take years for an introduced species to spread to the extent required to make a difference to pollination services, during which time any wild plants dependent on that pollinator may have already been lost. Changes in honeybees are also difficult to reverse quickly, as once a disease or pest becomes endemic the high density of hives allows easy spread.

6. Knowledge gaps.

As section 4 makes clear, there are very large gaps in the knowledge base on the economic value of pollination services. There is no robust evidence base on the marginal value of marketed output lost or gained due to changes in pollinator populations for a range of relevant crops. We also have no clue about the non-market economic benefits of increases in pollinator populations. This is in addition to a lack of knowledge of the ecosystem production functions that relate changes in ecosystems to changes in pollinators; or the agricultural production functions that relate changes in inputs of pollinator services to changes in yields. Given the extent to which the marginal value of pollinators is likely to be highly variable across crops and across the country, it is hard to state with confidence whether the widely-cited UK NEA (2011) figure of the value of pollination services in the UK is an over- or an under-estimate; whilst the figure is of no use anyway in a national income accounting sense (Nordhaus, 2006).

Indeed, a number of major data and knowledge gaps prevent a comprehensive assessment of national pollination service stocks. Foremost, pollination services are a product of visitation rate and quality. Although data on pollinator species diversity can be inferred from natural history records (Carvalheiro et al, 2013), to date little information is available on pollinator abundance due to the lack of a focused monitoring effort. Monitoring effects should audit both the number of managed colonies across the UK, and enable more accurate estimation of the population sizes of bumblebees and other wild pollinators. Instead, most work on assessing pollinator stocks is based on potentially suitable habitat for pollinator forage and nesting resources or using proxies based on data for managed honeybees which have also not been monitored in a consistent way at the national level

(Lonsdorf et al, 2009; Breeze et al, 2011, Schulp et al, 2013). The lack of monitoring has meant that these models have yet to be validated. Secondly, the presence of pollinators is not necessarily proportional to service provision as there may not be crops that require pollination within the local forage range. Similarly due to the differing forage preferences (e.g. Mayer and Lunden, 1991), activity periods (e.g. Tuell and Isaacs, 2010), morphological characteristics (e.g. Field Beans - Free, 1993) and synergistic behaviours of pollinators (e.g. Strawberry - Chagnon et al, 1993), local insects supported by the habitat may not be effective pollinators of neighbouring crops. Environmental factors, currently not incorporated into existing theoretical models of pollinator distribution, will also influence pollinator activity (Brittan et al, 2013). Finally, long term crop and landscape patterns may affect the functional pollinator community. For example increased inter-species competition caused by large scale oilseed rape can reduce populations of long-tongue bumblebees (Diekotter et al, 2010) which are the principle pollinators of field beans (Free, 1993).

Although existing theoretical models may be a useful proxy in the short term, dedicated long term data on local pollinator abundance and diversity will be essential to long-term accounting of pollination services in natural capital. A recent estimate of the costs of an effective, minimal cost protocol of sampling suggested that the total costs would be approximately £1.25M over 5 years (LeBuhn et al, 2013). This should ideally be informed by more comprehensive data on the effective pollinators of different UK crops, however as estimating the role of specific species and their presence or absence within the landscape will be very time consuming, a traits based approach, based upon the common foraging, morphological and life history traits of effective pollinators would likely be more readily implemented. Much of the information on the traits of particular pollinators is already available, greatly simplifying this process and has been used effectively to predict species response to disturbance (Williams et al, 2010).

Finally, Nordhaus (2006) cautions that we probably do not want to try and include all non-market goods in the national accounts, but only those which we think are most important from a policy-making viewpoint, and/or those which are experiencing rapid change. Pollination services from commercial and wild pollinators might well fit both of these criteria. Unfortunately, the evidence base is too small to say for sure right now.

References

Allsopp, M.H., W.J. de Lange, and R. Veldtman (2008), Valuing Insect Pollination Services with Cost of Replacement. *PLoS ONE*, **3** (9)

Barbier, E.B. (2012) "Ecosystem Services and Wealth Accounting" in *Inclusive Wealth Report 2012*. UNEP.

Baumgartner, S., (2007) The insurance value of biodiversity in the provision of ecosystem services. *Natural Resource Modelling,* 2007. **20**: p. 87-127.

Bommarco R., Kleijn D. and Potts S.G. (2013) Ecological intensification: harnessing ecosystem services for food security; *Trends in Ecology and Evolution* ***28***, 230-238

BREEZE, T.D., BAILEY, A.P., BALCOMBE, K.G. and POTTS, S.G., 2011. Pollination services in the UK: How important are honeybees?*Agriculture Ecosystems & Environment,* **142**(3-4),.

Brittan C., Kremen C. and Klein A.M. (2013b) Biodiversity buffers pollination from changes in environmental conditions; *Global Change Biology* ***19***, 540-547

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** (5): e37235

Carvalheiro L.G., Kunin W.G., Keil P., Aguirre-Gutierrez J., Ellis W.E., Fox R., Groom Q., Hennekens S., Landuyt W., Meas D., de Meutter F.V., Michez D., Rasmont P., Ode B., Potts S.G., Reemer M., Roberts S.P.M., Schaminee J., WallisDeVires M.F. and Biesmeijer J.C. (2013) Species Richness Declines and Biotic Homogenisation have Slowed Down for NW-European Pollinators and Plants; *Ecology Letters* ***16***, 870-878

Carvell, C., et al., (2007) Comparing the efficacy of agri-environment schemes to enhance bumble bee abundance and diversity on arable field margins. *Journal Of Applied Ecology* **44**(1): p. 29-40.

Chagnon M., Gingras J. and de Oliveira D. (1993) Complementary Aspects of Strawberry Pollination by Honey Bees and Indigenous Bees (Hymenoptera); *Journal of Economic Entomology* ***86***, (2), 416-420

Diekoetter T, Kadoya T, Peter F., Wolters V. and Jauker F. (2010). Oilseed rape crops distort plant-pollinator interactions. *Journal of Applied Ecology,* **47**(1), pp. 209-214.

Delaplane K. S. and Mayer D. E. (2000) *Crop Pollination by Bees,* CABI Publishing; Wallingford

Diekötter T., Kadoya T., Peter F., Wolters V. and Jauker F. (2010) Oilseed Rape Crops Distort Plant-Pollinator Interactions; *Journal of Applied Ecology 47*, (1), 209-214.

Ellis C., Goulson, D., Breeze, T. and Hanley N. (2013) "Pollination Services" in *A Natural Capital Asset Check.* London: Eftec.

Free J. (1993) *Crop Pollination by Insects* (2nd Edition); Academic Press, London

Gallai, N., et al., (2009) Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics,* **68** (3): p. 810-821

Garibaldi, L.A., et al., *Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance.* Science, 2013

Garrat M.P., et al., (2013) Avoiding a bad apple: insect pollination enhances fruit quality and economic value. *Agriculture Ecosystems and Environment,* forthcoming.

Goulson, D., (2013) An overview of the environmental risks posed by neonicotinoid insecticides. *Journal of Applied Ecology*, 2013. **50** (4): p. 977-987.

Goulson, D., et al., (2002) Colony growth of the bumblebee, Bombus terrestris, in improved and conventional agricultural and suburban habitats. *Oecologia*, **130** (2): p. 267-273

Greasley, D, et al (2013) "Testing the predictive power of genuine savings" University of Stirling, Discussion Papers in Economics.

Hoehn, P. et al (2008) "Functional group diversity of bee pollinators increases crop yields" *Proceedings of the Royal Society B,* 275, 2283-2291.

Holzschuh A., Dormann C. F., Tscharntke T. and Steffan-Dewenter I. (2011) Expansion of mass-flowering crops leads to transient pollinator dilution and reduced wild plant pollination; *Proceedings of the Royal Society of London - B. Biological Science* ***278***, 3444-3451.

Jauker F., Peter F, Wolters V. and Diekotter T. (2012) Early reproductive benefits of mass-flowering crops to the solitary bee Osmia rufa outbalance post-flowering disadvantages; *Basic and Applied Ecology* ***13***, 268-276

Klein, A.M. et al (2007) Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B-Biological Sciences,* **274** (1608): p. 303-313.

Kleijn, D. and I. Raemakers, (2008) A retrospective analysis of pollen host plant use by stable and declining bumble bee species. *Ecology,* **89** (7): p. 1811-1823

LeBuhn G., Droege S., Connor E.F., Gemmill-Herren B., Potts S.G., Minckley R.L., Griswold T., Jean R., Kula E., Roubik D.W., Cane J., Wright K.W., Frankie G. and Parker F. (2013) Detecting Insect Pollinator Declines on Regional and Global Scales; *Conservation Biology* ***27***, 1-13

Lonsdorf E., Kremen C., Ricketts T., Winfree R., Williams S. and Greenleaf S. (2009) Modelling pollination services across agricultural landscapes; *Annals of Botany* ***103***, 1589-1900

Mayer D.F. and Lunden J.D. (1991) Honey bee foraging on dandelion and apple in apple orchards; *Journal of the Entomological Society of British Columbia* ***88***; 15-17

Nordhaus W. (2006) "Principles for national accounting for nonmarket assets" in Jorgensen et al (eds.) *A New Architecture for the US National Accounts.* Chicago: University of Chicago Press.

Ollerton, J., Winfree, R., Tarrant, S., (2011) How many flowering plants are pollinated by animals? *Oikos* ***120,*** (3), 321–326.

Osgathorpe L, Park K., Goulson D., Acs S and Hanley N (2011) "Trade-offs between agriculture and biodiversity in marginal areas" *Ecological Economics*, 70 1162–1169

Pearce D.W. and Atkinson G. (1993) Capital theory and the measurement of sustainable development: an indicator of weak sustainability. *Ecological Economics* 8: p. 103-108.

Pywell R.F., Meek W.R., Loxton R.G., Nowakowski M., Carvell C. and Woodcock B.A. (2011) Ecological restoration on farmland can drive beneficial functional responses in plant and invertebrate communities; *Agriculture Ecosystems and Environment* ***140***, 62-67

Schulp C.J.E., Lautenbach S. and Verburg P.H. (2014) Quantifying and mapping ecosystem services: Demand and supply of pollination in the European Union; *Ecological Indicators* ***36***, 131-141

Tuell J.K. and Isaacs R. (2010) Weather during Bloom affects pollination and yield in highbush blueberries; *Journal of Economic Entomology* ***103***, (3), 557-562

Vanbergen A., Heard M., Breeze T., Potts S. and Hanley N. (2013) *Status and Value of Pollinators and Pollination Services.* Report to DEFRA.

Whitehorn, P.R., et al., (2012) Neonicotinoid pesticide reduces bumble bee colony growth and queen production. *Science,* **336**: p. 351-352

Williams N.M., Crone E.E., Roulston T.H., Minckley R.L., Packer L. and Potts S.G. (2010) Ecological and life-history traits predict bee species response to environmental disturbances; *Biological Conservation* ***143***, (10), 2280-2291.

Willmer, P.G., Bataw, A.A.M. and Hughes, J.P., (1994). The Superiority of Bumblebee to Honeybees as Pollinators - Insect Visits to Raspberry Flowers. *Ecological Entomology,* **19**(3)

Winfree, R., B.J. Gross, and C. Kremen, (2011) Valuing pollination services to agriculture. *Ecological Economics,* **71**: p. 80-88