

Pollination services in the UK: how important are honeybees?

Article

Accepted Version

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 and Environment*, 142 (3-4). pp. 137-143. ISSN 0167-8809 doi: 10.1016/j.agee.2011.03.020 Available at <http://centaur.reading.ac.uk/25072/>

It is advisable to refer to the publisher's version if you intend to cite from the work.

To link to this article DOI: <http://dx.doi.org/10.1016/j.agee.2011.03.020>

Publisher: Elsevier

All outputs in CentAUR are protected by Intellectual Property Rights law, including copyright law. Copyright and IPR is retained by the creators or other copyright holders. Terms and conditions for use of this material are defined in the [End User Agreement](#).

www.reading.ac.uk/centaur

CentAUR

Central Archive at the University of Reading

Reading's research outputs online

Research Impact Manager
Dr Anthony Atkin
+44 (0)118 787411
a.atkin@reading.ac.uk

Research & Enterprise

Whiteknights House
Whiteknights
Reading RG6 6AH

phone +44 (0)118 8628
fax +44 (0)118 378 8979
email impact@reading.ac.uk

25 June 2014

Pollination services in the UK: How important are honeybees? *Agriculture, Ecosystems and Environment*, Breeze, T. D., Bailey, A. P., Balcombe, K. G. and Potts, S. G. (2011) **142** (3-4). pp. 137-143

Dear Downloader,

Thank you for downloading this publication from our repository.

The University of Reading is committed to increasing the visibility of our research and to demonstrating the value that it has on individuals, communities, organisations and institutions.

To support us in this commitment, we are running a pilot project to find out more about the people who download information from the University of Reading website. The publication you have downloaded is part of this project.

It would help us greatly if you could spend **two minutes** filling out the survey at the following link. Completion is voluntary and information supplied will be treated as confidential. Please indicate if you would be happy for us to contact you in the future. Alternatively, enquiries or responses can be addressed to impact@reading.ac.uk

<https://www.surveymonkey.com/s/GJRJ5GR>

Thank you for your interest in our research and we look forward to receiving your feedback.

Yours sincerely

Anthony Atkin, Research Impact Manager (University of Reading)

Pollination services in the UK: How Important are Honeybees?

Breeze T.D.^{1*}, Bailey A.P.² Balcombe K.G.³ and Potts S.G.¹

Abstract

Pollination services are known to provide substantial benefits to human populations and agriculture in particular. Although many species are known to provide pollination services, honeybees (*Apis mellifera*) are often assumed to provide the majority of these services to agriculture. Using data from a range of secondary sources, this study assesses the importance of insect pollinated crops at regional and national scales and investigates the capacity of honeybees to provide optimal pollination services to UK agriculture. The findings indicate that insect pollinated crops have become increasingly important in UK crop agriculture and, as of 2007, accounted for 20% of UK cropland and 19% of total farmgate crop value. Analysis of honeybee hive numbers indicates that current UK populations are only capable of supplying 34% of pollination service demands even under favourable assumptions, falling from 70% in 1984. In spite of this decline, insect pollinated crop yields have risen by an average of 54% since 1984, casting doubt on long held beliefs that honeybees provide the majority of pollination services. Future land use and crop production patterns may further increase the role of pollination services to UK agriculture, highlighting the importance of measures aimed at maintaining both wild and managed species.

Keywords

Pollination Services

Honeybees

Ecosystem Services

Crop Pollination

1. Introduction

Human societies derive great benefit from a range of natural ecological functions, referred to as ecosystem services. Insect mediated pollination, the transfer of pollen within or between flowers via insect vectors, is one such ecosystem service, regulating a range of direct and indirect benefits to human societies (Fisher *et al*, 2009). Insect pollination is thought to benefit the yields of 75% of globally important crop species and is responsible for an estimated 35% of world crop production (Klein *et al*, 2007). The nature and extent of these benefits can vary between crops, ranging from increasing the quantity and quality of fruit or seed produced to hastening crop development and increasing genetic diversity within crop species (Free, 1993; Shipp *et al*, 1994; Hajjar *et al*, 2008). Economically, the value of insect pollination services to crop agriculture has been estimated at ~£400 million per annum within the UK (POST, 2010) and €153 billion per annum

¹ Centre for Agri Environmental Research, University of Reading, Reading RG6 6AR, UK

² School of Agriculture, Policy and Development, Department of Agriculture, University of Reading

³ School of Agriculture, Policy and Development, Department of Food Economics & Marketing, University of Reading

1 globally (Gallai *et al*, 2009). Insect pollination services are also essential to propagating numerous
2 wild plant species (Ollerton *et al*, In Press), many of which contribute to human welfare indirectly as
3 important components of landscape aesthetics (Willis and Garrod, 1993). Other insect pollinated
4 wild plants, such as hawthorn (*Crataegus monogyna*), provide important winter forage for farmland
5 birds and other wildlife (Jacobs *et al*, 2009) that contribute to human welfare through more indirect
6 non-use values. Bees (*Apidae*) are generally regarded as the most important pollinators, in particular
7 an estimated 80% of global agricultural pollination services are attributed to the domesticated
8 European Honeybee (*Apis mellifera*) (Carreck and Williams, 1998). Furthermore, several other bee
9 species, such as the buff-tailed Bumblebee (*Bombus terrestris*), have recently been commercially
10 domesticated for large scale agricultural pollination (Delaplane and Mayer, 2000). However, a
11 growing body of research indicates that wild pollination services could account for a substantially
12 greater proportion of pollination services than previously thought, even in modern, intensive farm
13 systems (e.g. Winfree *et al*, 2008) prompting some to suggest that the importance of honeybees in
14 providing pollination services may have been over estimated (Westerkamp and Gottsberger, 2000).

15 Concerns regarding the stability of pollination services have existed for as long as the
16 concept of ecosystem services themselves (Nabhan and Buchman, 1997). Although some have
17 claimed that these concerns are exaggerated (Ghazoul, 2005), there has recently been mounting
18 evidence of a global decline in wild pollinator populations (Potts *et al*, 2010a) and honeybee hive
19 numbers are now thought to be in a long-term state of decline in many developed nations (Potts *et al*
20 *et al*, 2010b; vanEngelsdorp and Meixner, 2010). Furthermore, although global honeybee hives
21 numbers have grown by ~45% since 1961, the area of insect pollinated crops has grown by >300% in
22 the same period, now accounting for 6.1% of global crop land (Aizen and Harder, 2009). While trends
23 in global yields do not demonstrate any significant global pollination shortage (Aizen *et al*, 2008),
24 regional declines have been associated with localised shortfalls in pollinator populations (Steffan-
25 Dewenter *et al*, 2005). Within Europe, the UK has experienced particularly well documented
26 pollinator losses, with widely recorded declines in the diversity and distribution of wild bees,
27 butterflies, hoverflies and wild plants during the last 50 years (Biesmeijer *et al*, 2006; Thomas *et al*,
28 2004; Carvell *et al*, 2006) and a 54% fall in honeybee hive numbers in England between 1985 and
29 2005 (Potts *et al*, 2010b), raising concerns over the long-term stability of UK pollination services.

30 Although pollination services provide substantial benefits to UK crop producers and
31 consumers, there have been few published accounts of the extent and distribution of these benefits
32 across the UK. In order to bridge this gap, this study examines the proportion of UK crop area and
33 market value stemming from crops which benefit from insect pollination so as to gauge how
34 important insect pollinated crops are to UK agriculture. Similarly, although it is widely assumed that
35 honeybees provide the majority of pollination services currently no research has demonstrated the
36 validity of this speculation. While recent studies have suggested that honeybees may not always be
37 optimal or even effective pollinators of certain crops (e.g. Apples; Thomson and Goodell, 2001), they
38 are easily managed, are active earlier in the year than many wild pollinators, and can be moved
39 between crops in bloom (Delaplane and Mayer, 2000). As such, honeybees can provide invaluable
40 pollination services in the intensively managed systems that typify UK cropland. Declining numbers
41 of honeybee hives during the last 20 years therefore have serious implications for both the provision
42 of pollination services and the UK's ability to cope with changing demand for pollination services.
43 This study explores this potential deficit by examining trends in the potential of UK honeybees to

1 supply demands for pollination services at a level where yield and quality benefits to crops are
2 maximised.

3 2. Methods

4 2.1. The importance of insect pollinated crops to UK agriculture

5 A total of 19 crops and crop groups recorded by the Department for Environment Food and
6 Rural Affairs (DEFRA) which benefit from insect pollination to any extent were identified using Klein
7 *et al* (2007) (Appendix 1). While certain varieties of some crops such as oilseed rape (*Brassica napus*)
8 and cucumber (*Cucumis sativus*) are entirely self-fertile and do not require insect pollination (Free,
9 1993), it is assumed that only insect pollinated varieties are utilised, primarily because varietal data
10 is unavailable for most crops (DEFRA, 2010a; 2009) and data on the pollination requirements of most
11 varieties are also unavailable. The proportion of crop area and value derived from insect pollinated
12 crops was estimated at a national level using data for all food and non-food crops reported in the
13 2008, 2000 and 1996 Basic Horticultural Survey (DEFRA, 2009; Ministry of Agriculture Fisheries and
14 Food - MAFF, 1999, 1996) and the Agriculture in the UK report (DEFRA, 2010a). While area and value
15 data for horticultural crop groups are reported in DEFRA (2010a), data from DEFRA, (2009) and
16 MAFF (1999, 1996) are used to allow for assessment of trends on a per crop basis. Although area
17 data reported in DEFRA (2009) and MAFF (1999, 1996) is estimated for crop years it is approximately
18 consistent with calendar year fresh fruit area data found in DEFRA (2010a). 1984 horticultural crop
19 area data was taken as calendar year data from MAFF (1995) and adjusted by the average difference
20 between crop and calendar year area data for years also reported in MAFF (1996). All value data
21 were reported for calendar years and represent value paid to producers, not necessarily final market
22 prices. The value of changes in stock and subsidies for arable crops were not included (DEFRA,
23 2010a).

24 At a regional level, crop specific data from the June censuses of each constituent country
25 (England - DEFRA, 2008a; Scotland – Scottish Government, 2007; Northern Ireland - Department of
26 Agriculture and Rural Development - DARD, 2008) and the orchard fruit and glasshouse surveys
27 (DEFRA, 2007b, 2008b) were used to estimate the percentage of individual crop occurring within
28 each region. Further crop specific area data concerning soft fruits and pulses were provided by
29 members of the census teams (H. Hout, L. Reid, C. McCormack, Pers. comm., 2009). As crop specific
30 data is not collected for any insect pollinated crops in Wales, no analysis of the pollinator
31 dependence of the country could be conducted (Welsh Assembly Government, 2008). For the census
32 category Peas and Beans, which includes both insect pollinated and non-insect pollinated crops, this
33 area was divided proportionately between the constituent crops based on their total national area
34 reported in DEFRA (2009). Any orchard fruit or glasshouse crop area not specifically allocated in
35 DEFRA (2007b, 2008b) was distributed among the remaining counties, weighted by their total area
36 of top fruit or protected vegetables reported in DEFRA (2008a), Scottish Government (2007) and
37 DARD (2008). These procedures assume that all crops can be grown in all regions, however, the
38 range of climates across the UK will likely have a substantial influence upon farmers ability to grow
39 some crops, particularly fruits. The percentage of each crop occurring within each region was then
40 multiplied by the area and value of each crop as reported by DEFRA (2009, 2010a) which, in some
41 cases, differ substantially from DEFRA (2008a) and DEFRA (2007a, 2008b) due to differences in
42 survey methodology. Where areas of individual crops were not identified by any source, for example

1 open grown vegetables which are only reported as a group, the sum market value of all crops within
2 the group were used to estimate regional value. Mushrooms were excluded from this study as their
3 planted area is not reported at either a national or regional level by any of the sources above,
4 although their economic value is substantial (£104m in 2007; DEFRA, 2009). All value figures were
5 inflated to 2007 values using consumer price indices (ONS, 2009).

6 2.2. Pollination service capacity of UK Honeybees

7 The maximum capacity of honeybees to satisfy optimal pollination service demand
8 ($OPC_{max,t}$), a ratio of effective total honeybee hives over total pollination service demand from UK
9 crops was estimated mathematically; let c = crop, t = year and p = phenological (flowering) period
10 (1...P) within t , each representing a month long interval, beginning from mid-March until mid-June. P
11 is determined based on the number of different crops a beekeeper could move their hives between
12 within a single t . P is assumed to be 3 as this is maximum number of crops a professional beekeeper
13 will be able to move between in a year (John Howat, Pers. Comm., 2010). Although varieties of some
14 crops may bloom after this end point (e.g. Wagstaffe and Battey, 2006) varietal data is not available
15 for most crops and therefore could not be incorporated. A_{ctp} represents the area of each crop grown
16 in each p within t (as reported by DEFRA 2009, 2010a). Areas of crops listed as Glasshouse Crops, i.e.
17 those grown exclusively in fully enclosed glasshouses (tomatoes, cucumbers and sweet peppers)
18 were excluded as honeybees are seldom used in such environments due to management difficulties
19 (Delaplane and Mayer, 2000). Crops grown under partially enclosed poly-tunnels, such as
20 strawberries, were included in this area as honeybees can be used in such systems and estimates of
21 the applicable area is not available for each year under consideration. R_c represents the
22 recommended hive density for optimal pollination of crop c as derived from published sources
23 (Appendix 1). D_{tp} is the total pollination services demanded (expressed in number of honeybee
24 hives) in each p within each t , defined as:

25 H_t represents the reported number of managed UK honeybee hives (as reported by MAFF and the
26 National Bee Unit, see Potts *et al*, 2010b). In years where H_t is not formally reported for one or more
27 constituent nations then it is assumed hive numbers have remained constant between t and $t-1$.
28 Under this assumption, which differs from those employed in Potts *et al*. (2010b), total hive numbers
29 in the UK have grown by 22% since 1984 to 289,750 in 2007, however this number remains constant
30 from 2002 onwards. In the absence of data on stocking practices, growers are assumed to stock no
31 more than R_c per hectare. E_{tp} represents hives in excess of those required in phenology period p
32 and is calculated as:

33 S_t representing the effective total pollination services supplied by H_t is defined as

1 Where $I_{tp} = 0$ if $E_{tp} < 0$ and 1 otherwise. Consequently, $0 \leq Q_t \leq PH_t$. Under these definitions $OPC_{max,t}$ is
2 defined as:

3 OPC_{max} was recalculated at a range of R_c , representing the lowest, highest and average
4 recommended hive density per hectare. National area of winter sown oilseed rape was acquired
5 from DEFRA (2010b) and Houlst H. pers. comm. (2010) with an average area applied to each year not
6 reported.

7 3. Results

8 3.1. The importance of insect pollinated crops to UK agriculture

9 Analysis of cropland in the UK since 1984 indicates that insect pollinated crop area has risen
10 by 57.5% covering 848,946ha of UK cropland in 2007, growing at an average rate of 21,250 ha per
11 year (Figure 1A). This represents 20.4% of 2007 UK cropland, more than double the proportion of
12 total crop land occupied by these crops in 1984 (7.2%, Figure 1C). The exclusion of insect pollinated
13 minority crops, such as Borage, and the indirect techniques used to produce horticultural crop area
14 estimates (DEFRA, 2010c) will influence this finding to an unknown extent, however, the magnitude
15 of these effects is likely too small to significantly affect the findings. Much of this growth stems from
16 substantial rises in oilseed rape and field bean area, collectively rising by 503,000ha since 1984
17 (DEFRA, 2010a) at the expense of barley and other arable crops. In comparison, the area of fruit
18 crops, all of which benefit from insect pollination, has fallen by ~17,900 ha during the same period
19 with particularly sharp declines in dessert and culinary apples, likely due to falling prices/tonne and
20 increased costs (Nix, 1984, 2010; DEFRA, 2009; MAFF, 1999, 1996). These results are distorted
21 somewhat by a spike in the area of oilseed rape in 2007, which has since returned to levels similar to
22 previous trends (DEFRA, 2010a). Overall, the total area of cropland in the UK has fallen by 831,366ha
23 within the same period, with particularly strong declines in the area of barley (-54.6%), potatoes (-
24 29.3%) and other vegetable crops (-23.6%). Much of this land has become pastureland, although
25 ~61,000ha of total agricultural land have been taken out of production (DEFRA, 2010a).

26 Regionally, South East England has the greatest area of insect pollinated crops, occupying
27 ~30% of cropland (Table 1) due to large areas of fruit growing within the region (DEFRA, 2008a). In
28 spite of these rises in insect pollinated crop area, by 2007 the total value of insect pollinated crops
29 has fallen by £626M (2007 £) since 1984 to £1057M (Figure 1B) as a result of falling prices and
30 declining planted area of high yielding fruit crops such as tomatoes and dessert apples. This trend is
31 in part a product of the methodology used; while prices for insect pollinated crops have grown by an
32 average of 102% since 1984, this growth is substantially smaller than the growth in inflation (231%
33 cumulative) by which crop value was adjusted. Consequently when unadjusted for inflation, this
34 overall downward trend is reversed, with total value of insect pollinated crops rising by £329M since
35 1984. Nonetheless, the proportion of total crop value represented by these crops has grown, albeit
36 inconsistently, from 15.1% in 1984 to 19.3% in 2007 (Figure 1D) due also to widespread increases in
37 oilseed rape and field bean production in place of other arable crops (DEFRA, 2010a). At a regional
38 scale, insect pollinated crops represent the greatest proportion of crop value in South East England,
39 the West Midlands, and Northern Ireland. However, their absolute value was greatest in Eastern

1 regions of England (Table 1). This disparity stems from varying scales of agriculture between regions
2 and the higher per hectare value of fruit crops, which are commonly grown in eastern regions,
3 compared to arable crops (DEFRA, 2009, 2010a).

4 3.2. The pollination service capacity of UK honeybees

5 In spite of growth in honeybee hives arising from the assumptions made in this study, the
6 capacity of honeybees to supply pollination service demands (OPC_{max}) has fallen by more than 50%
7 during the study period from a peak 70.3% in 1984 to 34.1% by 2007 (Figure 2). This trend is a
8 product of substantial growth in insect pollinated crop area, particularly oilseed rape and field
9 beans, each of which requires several hives per hectare to ensure optimal pollination. Under higher
10 recommended density assumptions, managed honeybees may only contribute as little as 11.7% of
11 optimal pollination services. In all years, only a small proportion (1-11%) of available hives are
12 required in the first phenological period and sufficient hive numbers are available throughout the
13 year to provide optimal pollination services to UK fruit crops (Appendix 1). Regionally demand for
14 pollination services, in terms of total hives required, is greatest in Eastern regions of the UK (Table 2)
15 which, as highlighted above, have higher areas of insect pollinated crops (DEFRA, 2008a).

16 [Figure 1]

17 [Table 1]

18 [Table 2]

19 [Figure 2]

20 4. Discussion

21 4.1. Trends in insect pollinated crops

22 This study indicates that insect pollinated crops have become an increasingly substantial
23 component of UK crop agriculture since 1984, accounting for ~20% of UK crop land and ~19% of
24 total crop value in 2007. Much of this growth stems from rising areas of mass flowering arable crops,
25 likely due to past Common Agricultural Policy subsidisation. Oilseed rape has also benefited from
26 rising EU demands for biofuels (Stoate *et al*, 2009) and the advent of cultivars with low
27 glucosinolates and erucic acid content, allowing for use as animal feed (Burgess and Morris, 2009).
28 Fruit crops have also become more important to total UK crop value thanks to advances in growing
29 systems and, in the case of strawberries, breeding cultivars that bear fruit outside of the normal
30 growing season (Wagstaffe and Battey, 2006).

31 4.2. Trends in the pollination service capacity of UK honeybees

32 In spite of growing demand for pollination services and rising hive numbers, the OPC_{max} of
33 honeybees has declined by more than 50% since 1984 and will fall further if recent honeybee
34 declines are considered (see Potts *et al*, 2010b). This finding is subject to a set of potentially
35 distorting assumptions. First, most data on managed honeybee hive numbers are taken from
36 member information provided by beekeeping organisations and as such excludes hives managed by
37 non-members. Second, feral honeybee colonies are not included in these estimates as their
38 distribution and abundance are largely unknown and consequently their impact upon pollination

1 services cannot currently be estimated (Carreck, 2008). Third, as highlighted in the methodology, the
2 area of each crop was assumed to solely comprise of insect pollinated varieties, possibly
3 exaggerating the area of crops requiring insect pollination. Each of these assumptions may produce
4 an underestimation of actual pollination services provided by honeybees. By contrast, a number of
5 other factors can exaggerate the OPC_{max} of honeybees. Foremost, in light of the sharp decline in
6 honeybee hive numbers reported in Potts et al (2010b), the assumptions made regarding hive
7 numbers in years where no official reports were available are likely to produce overestimations in
8 recent years. Furthermore, the recommended hive density values are derived from a wide range of
9 sources from different countries and methods (Delaplane and Mayer, 2000). While these values are
10 seldom specific for the UK, they are generally accepted to be appropriate and have rarely been
11 challenged. Colonies were assumed to be at optimal health, ignoring the potential impacts of pests
12 and diseases upon foraging activity (Ellis *et al*, 2003 but see Ellis and Delaplane, 2008). Although data
13 on honeybee disease incidence are available from the National Bee Unit, as inspection is voluntary
14 and there are few estimates of the relation between health and pollination efficiency, such data
15 cannot yet add meaningfully to the findings. Most critically, all UK honeybee hives were assumed to
16 be actively managed for pollination service provision throughout the crop year. In actuality, most UK
17 beekeepers are amateurs or professional honey producers that typically position their hives in
18 nectar rich semi-natural habitat, although some crops, such as apples are often cited as important
19 nectar sources for honey production (Carreck et al, 1997). Currently, only about 2% of UK hives
20 (~5,700) are known to be professionally managed for pollination services (John Howat, Pers. Comm.
21 2010), accounting for <0.5% of OPC_{max} even under lower required density assumptions. As other
22 beekeepers are unlikely to move their hives as often, reducing the value of P (see methodology)
23 from 3 to 2 may better reflect this, however, the large excess of hives in the first phenological period
24 implies that only a minority of hives are moved more than once. Finally, no account is made of the
25 contribution of other managed bees, such as the ~10,000 *B. terrestris* hives imported into the UK
26 each year (POST, 2010). As managed *B. terrestris* are most often used for pollination within fully
27 enclosed systems which are neither accessible to wild pollinators nor suitable to honeybees, their
28 inclusion is unlikely to affect conclusions reached.

29 4.3. Trends in insect pollinated crop yields

30 Contrary to the fall in the OPC_{max} of honeybees, per ha yields of insect pollinated crops have
31 risen by an average of 54% since 1984 (Figure 3). Regression analysis using R (R project, 2010)
32 indicates that average yields of insect pollinated crops as a group have grown at a significantly faster
33 rate per annum than other crops ($t= 3.611$, $P=<0.001$, see appendix 3 for details). The inconsistent
34 nature of honeybee hive data and substantial auto-correlation arising from the resultant
35 assumptions, prevents valid assessment of correlations between yields and honeybee numbers. In
36 line with findings by Aizen *et al*. (2008), the observed trends in yield suggest that there has not yet
37 been a detectable loss of pollination services within the UK. Subsequently, these findings infer that
38 wild bee populations may make a much greater contribution to UK crop pollination services than
39 previously thought. This is somewhat speculative given the observed declines in wild bees during the
40 study period (Biesmeijer *et al*, 2006; Carvel *et al*, 2006), although as many wild bees can be
41 substantially more effective pollinators than honeybees (e.g. Thompson and Goodall, 2001) it is
42 possible that, even in reduced abundance, these species can provide effective pollination services to
43 crops. Furthermore, increased availability of mass floral resources (Diekötter *et al*, 2010), may have
44 created a population sink effect in wild bees in light of reduced competition from honeybees

1 (Goulson and Sparrow, 2009) and declining wildflower availability (Biesmeijer *et al*, 2006).
2 Alternatively, intensification and agronomic advances, such as increasing fruit tree density and
3 selection of higher yielding arable crop cultivars, might have enhanced yields sufficiently to mask
4 declines in pollination services. Growers may themselves have reacted to pollination service declines
5 by utilising more self-fertile or parthenocarpic cultivars. However, as pollination requirements are
6 seldom considered when developing new cultivars (e.g. Home Grown Crops Association, 2010) this
7 seems unlikely. Under these circumstances, honeybees may be more major contributors to
8 pollination services than is apparent from the data presented here. Another possibility is that
9 pollination service deficits may only have arisen in a few crops which honeybees are rarely employed
10 to pollinate, such as mass flowering arable crops (John Howat, Pers. Comm. 2010). This is supported
11 in part by the 10-22% decline in field beans, oilseed rape and linseed yields (Appendix 2) since 1984.

12 [Figure 3]

13 4.4. Future demand for insect pollinated crops

14 A number of market factors and policy are likely to influence the future importance of
15 pollination services to UK crop agriculture. Firstly, demand for oilseed rape may rise further as ~1.4
16 million ha of the crop is required to meet the UKs EU 2020 biodiesel target (Foresight Land Use
17 Futures Project, 2010) although non-controllable pest and disease species are likely to restrict the
18 regularity with which it can be included in rotations (Berry and Spink, 2006). Similarly, although the
19 UK has become increasingly reliant upon low-cost imports to satisfy demand for many insect
20 pollinated crops (DEFRA, 2009), demand for locally sourced produce, arising from perceived
21 environmental, economic and health benefits (Brown *et al*, 2009) may bolster the market for home
22 production of many crops. Finally, government policy aimed at improving dietary health is projected
23 to encourage a substantial rise in the area of fruit crops, particularly in southern and eastern regions
24 of England, at the expense of pasture farming, field bean and oilseed area as demand for meat and
25 feed falls (Arnoult *et al*, 2010). Accordingly, insect pollinated crops account for a lower proportion of
26 crop area under this scenario compared to the reference run.

27 4.5. Conservation recommendations

28 In light of the current and potential future importance of insect pollination, bee
29 conservation efforts are likely to produce substantial long-term benefits to UK agriculture. The
30 findings of this study suggest that these efforts should be focused on a suite of wild and managed
31 pollinators, rather than over-relying on honeybees as sole service providers. Currently there is no
32 national UK conservation policy targeted towards pollination services, however, recent government
33 investment in pollination research (POST, 2010) combined with a shift towards ecosystem oriented
34 conservation (DEFRA, 2007b) are promising first steps. While current agri-environmental schemes
35 provide some options that are beneficial to pollinators, such as nectar flower mixes (Potts *et al*,
36 2009), without added incentives, these options suffer from poor uptake compared to lower-cost
37 alternatives (Hodge and Reader, 2010). Clearly defined, quantifiable ecosystem service outputs and
38 specific incentives for more beneficial activities are likely to eliminate this shortcoming, creating a
39 cost-effective market for the production of pollination and other ecosystem services (Smith, 2006).
40 Unfortunately, primary conservation research seldom translates into effective policy as political
41 actors often fail to act on an effective time scale (Knight *et al*, 2006) or to the required extent (Wu *et al*,
42 2003). As such, it is essential that future research demonstrate the benefits of pollination services

1 to growers, particularly for crops which benefit in a significant but less overt manner, such as oilseed
2 rape (Klein *et al*, 2007), to encourage them to adopt pollinator conservation measures.

3 As wild pollinator populations often lack the abundance necessary to pollinate intensive,
4 large-scale crop systems and their population dynamics can vary strongly between years (e.g. Rader
5 *et al*, 2009), honeybees are likely to remain an important component of UK pollination services.
6 Apiculture is a declining industry in the UK (Potts *et al*, 2010b) and therefore securing and expanding
7 honeybee populations will probably entail substantial increases in payments for pollination services,
8 particularly for crops such as oilseed rape where beekeepers seldom receive payment (Carreck *et al*,
9 1997) in order to provide sufficient incentives to beekeepers. Although producer willingness to pay
10 for these services may rise with increasing demand, these increased costs, which are vulnerable to
11 price shocks in years of disease outbreak (Sumner and Boriss, 2006), combined with rising prices for
12 inputs (Nix, 2010) may dissuade many producers. Expanded use of other pollinating insects, such as
13 bumblebees or red mason bees (*Osmia rufa*), which are purchased rather than rented, may provide
14 growers with a more-cost effective means of ensuring optimal pollination services, particularly when
15 honeybees are sub-optimum pollinators of a particular crop (Delaplane and Mayer, 2000).
16 Geographically specific standardised assessments of optimal pollination requirements for different
17 crop cultivars will also be necessary to ensure producers and beekeepers are able to maximise the
18 service provision by managed pollinators. Nevertheless, the use of any managed pollinators should
19 be undertaken with considerable caution as their release can influence forage resources (Goulson
20 and Sparrow, 2009), disease prevalence (Colla *et al*, 2006) and population size (Stubbs and
21 Drummond, 2001) in nearby wild pollinator populations. Consequently, it is essential that wild
22 pollinator conservation policy evolves in parallel with a focused expansion of the UK beekeeping
23 industry in order to supply optimal pollination service demands to UK agriculture into the long-term
24 future.

25 5. Conclusions

26 This study has demonstrated that, in spite of rising demand for pollination services, the
27 capacity of UK honeybee populations to provide optimal pollination services has fallen dramatically
28 during the last 20 years. In contrast to expected trends, insect pollinated crop yields have risen
29 substantially during this time, implying that wild pollinators make a substantially greater
30 contribution to UK crop pollination services than previously assumed. These findings should be
31 treated with a degree of caution as the assumptions made may marginally under- or overestimate
32 the relative contribution of honeybees to actual pollination services. As insect pollinated crops are
33 likely to become increasingly important to UK agriculture in the immediate future, clarifying these
34 assumptions will be useful in directing new developments in effective pollination management at a
35 field and landscape scale.

36 6. Acknowledgements

37 The authors wish to acknowledge the invaluable data contributions of Helen Hault (DEFRA),
38 Linda Reed (Scottish Assembly Government) and Connor McCormac (DARD). John Howat of the Bee
39 Farmers Association provided crucial insight into the UK beekeeping industry and crop phenology.
40 Robin Dean of Red Beehive Pollination provided valuable contact information. Rex Brennan, Nick
41 Battey, Paul Hadley, Matthew Ordidge, Gillian Rose and Stuart Roberts provided links to information
42 on the phenology of crops. Fiona Underwood provided statistics support. Three anonymous referees

1 provided invaluable feedback on earlier drafts of the manuscript. Tom Breeze is supported by a
2 University of Reading Research Studentship. The research leading to these results has received
3 partial funding from the European Community's Seventh Framework Programme (FP7/2007-2013)
4 under grant agreement no 244090, STEP Project (Status and Trends of European Pollinators,
5 www.step-project.net). The authors declare no conflict of interest.

6 7. References

- 7 Aizen M.A. and Harder L.D. (2009) The Global Stock of Domesticated Honey Bees is Growing Slower
8 than Agricultural Demand for Pollination; *Curr. Biol.* 19 (11) 915-918
- 9 Aizen M.A., Garibaldi L.M., Cunningham S.A. and Klein A.M. (2008) Long Term Trends in Crop Yield
10 and Production Reveal No Current Pollination Shortage but Increasing Pollinator Dependency; *Curr.*
11 *Biol.* 18 (20) 1-4
- 12 Arnoult, M H, Jones, P J, Tranter, R B, Tiffin, R, Traill, W B & Tzanopoulos, J (2010) Modelling The
13 Likely Impact of Healthy Eating Guidelines on Agricultural Production and Land Use in England and
14 Wales. *Land Use Policy* 27, (4), 1046-1055
- 15 Berry P.M. and Spink J.H. (2006) A Physiological Analysis of Oilseed Rape Yields: Past and Future; *J.*
16 *Agr. Sci.* 144, (5), 381-392
- 17 Biesmeijer, J. C., Roberts, S. P. M., Reemer, M., Ohlemuller, R., Edwards, M., Peeters, T., Schaffers, A.
18 P., Potts, S. G., Kleukers, R., Thomas, C. D., Settele, J. and Kunin, W. E. (2006) Parallel Declines in
19 Pollinators and Insect Pollinated Plants in Britain and The Netherlands; *Science* 313, (5785), 351-354
- 20 Brown E., Dury S. and Holdsworth M. (2009) Motivations of Consumers That Use Local, Organic Fruit
21 and Vegetable Box Schemes in Central England and Southern France; *Appetite* 53, (2), 183-188
- 22 Burgess P.J. and Morris J. (2009) Agricultural Technology and Land Use Futures: The UK Case; *Land*
23 *Use Policy* 26S, S222-S229
- 24 Carreck N. (2008) Are Honeybees (*Apis mellifera* L.) Native to the British Isles?; *J. Apicult. Res.* 47, (4),
25 318-322
- 26 Carreck N. and Williams I. (1998) The Economic Value of Bees in the UK; *Bee World* 79 (3), 115-123
- 27 Carreck N.L., Williams I. H. and Little D.J. (1997) The Movement of honey bee colonies for crop
28 pollination and honey production by beekeepers in Great Britain; *Bee World* 78, (2), 67-77
- 29 Carvell, C., Roy, D. B., Smart, S. M., Pywell, R. F., Preston, C. D. and Goulson, D. (2006) Declines in
30 Forage Availability for Bumblebees at a National Scale; *Biol. Conserv.* 132, (4), 481-489
- 31 Colla S.R., Otterstatter M.C., Gegear R.J. and Thomson J.D. (2006) Plight of the Bumblebee: Pathogen
32 Spillover from commercial to wild populations; *Biological Conservation* 129, (4), 461-467
- 33 Department of Agriculture and Rural Development (2008) Agricultural Census in Northern Ireland
34 2007; [http://www.dardni.gov.uk/index/publications/pubs-dard-statistics/agricultural-census-](http://www.dardni.gov.uk/index/publications/pubs-dard-statistics/agricultural-census-2007.htm)
35 [2007.htm](http://www.dardni.gov.uk/index/publications/pubs-dard-statistics/agricultural-census-2007.htm) Last Accessed 30/06/10; Last Updated 15/01/08

- 1 DEFRA (2007a) *Orchard Fruit Survey – February 2007*; DEFRA, London
- 2 DEFRA (2007b) *Conserving Biodiversity: The UK Approach*; DEFRA, London
- 3 DEFRA (2008a) June Survey of Agriculture and Horticulture 2007;
4 <http://www.defra.gov.uk/evidence/statistics/foodfarm/landuselivestock/junesurvey/results.htm>
5 Accessed 30/06/10; Last Updated 18/03/10
- 6 DEFRA (2008b) *Glasshouse Survey 2007*; DEFRA, London
- 7 DEFRA (2009) *Basic Horticultural Statistics 2009*
8 <http://www.defra.gov.uk/evidence/statistics/foodfarm/landuselivestock/bhs/2009/index.htm>
- 9 DEFRA (2010a) *Agriculture in the UK 2009*
10 <http://www.defra.gov.uk/evidence/statistics/foodfarm/general/auk/latest/index.htm> Accessed:
11 30/06/10, Last Updated 18/03/10
- 12 DEFRA (2010b) United Kingdom Cereal Yields 1885 onwards;
13 http://www.defra.gov.uk/evidence/statistics/foodfarm/food/cereals/documents/cyield_c.xls Last
14 Accessed; 30/06/10, Last Updated; 12/01/2010
- 15 DEFRA (2010c) *Basic Horticultural Statistics 2010*
16 <http://defra.gov.uk/evidence/statistics/foodfarm/landuselivestock/bhs/documents/bhs.pdf>
- 17 Delaplane K.S. and Mayer D.E. (2000) *Crop Pollination by Bees*, CABI Publishing; Wallingford
- 18 Diekötter T., Kadoya T., Peter F., Wolters V. and Jauker F (2010) Oilseed Rape Crops Distort Plant-
19 Pollinator Interactions; *J. Appl. Ecol.* 47, (1), 209-214
- 20 Ellis J.D., Hepburn R., Delaplane K.S., Neumann P. and Elzen P.J. (2003) The Effects of Adult Small
21 Hive Beetles, *Aethina tumida* (Coleoptera: Nitidulidae), on Nests and Flight Activity of Cape and
22 European Honey Bees (*Apis mellifera*); *Apidologie* 34, (4), 399-408
- 23 Ellis J.D. and Delaplane K.S. (2008) Effects of Nest Invaders on Honey Bee Pollination Efficacy; *Agr.*
24 *Ecosyst. Environ.* 127, (3-4), 201-206
- 25 Fisher B, Turner R.K. and Morling P. (2009) Defining and Classifying Ecosystem Services for Decision
26 Making; *Ecol. Econ.* 68, (3), 634-653
- 27 Fraser G.A. (2005) *An Analysis of Dormancy and Chilling of Ribes nigrum L.*; PhD Thesis, School of
28 Biological Sciences, University of Reading
- 29 Free J. (1993) *Crop Pollination by Insects* (2nd Edition); Academic Press, London
- 30 Gallai N., Salles, J. M., Settele, J. and Vaissiere, B. E. (2009) Economic Valuation of the Vulnerability of
31 World Agriculture Confronted with Pollinator Decline; *Ecol. Econ.* 68, (3), 810-821
- 32 Ghazoul J. (2005) Buzziness as Usual? Questioning the Global Pollination Crisis; *Trends Ecol. Evol.* (7)
33 367-373

- 1 Goulson D. and Sparrow K.R. (2009) Evidence for Competition Between Honeybees and Bumblebees;
2 Effects on Bumblebee Worker Size; *J. Insect Conserv.* 13, (2), 177-181
3
- 4 Hajjar R., Jarvis D.I. and Gemmill-Herren B (2008) The Utility of Crop Genetic Diversity in Maintaining
5 Ecosystem Services; *Agr. Ecosyst. Environ.* 123 (4) 261-270
- 6 Home Grown Crops Authority (2010) HGCA Recommended List – Winter Oilseed Rape 2011/12
7 East/West Region
8 http://www.hgca.com/document.aspx?fn=load&media_id=6719&publicationId=4821
- 9 Hodge I. and Reader M. (2010) The Introduction of Entry Level Stewardship in England: Extension or
10 Dilution in Agri-Environment Policy? *Land Use Policy* 27, (2), 270-282
- 11 Jacobs, J. H., Clark, S. J., Denholm, I., Goulson, D., Stoate, C. and Osborne, J. L. (2009) Pollination
12 Biology of Fruit Bearing Hedgerow Plants and the Role of Flower Visiting Insects in Fruit Set; *Ann.*
13 *Bot.* 104, (7), 1397-1404
- 14 Klein, A. M., Vaissiere, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C.,
15 Tscharntke, T. (2007) Importance of Pollinators in Changing Landscapes for World Crops; *P Roy Soc*
16 *B-Biol Sci* 274, (1608), 303-313
- 17 Knight A. T., Cowling R. M. and Campbell B. M. (2006) An Operational Model for Implementing
18 Conservation; *Conserv. Biol* 20, (2), 408-419
- 19 MAFF (1995) *Basic Horticultural Statistics for the United Kingdom Calendar and Crop Years 1984-*
20 *1994*; Ministry of Agriculture Food and Fisheries, London
- 21 MAFF (1996) *Basic Horticultural Statistics for the United Kingdom Calendar and Crop Years 1985-*
22 *1995*; Ministry of Agriculture Food and Fisheries, London
- 23 MAFF (1999) *Basic Horticultural Statistics for the United Kingdom Calendar and Crop Years 1988-*
24 *1998*; Ministry of Agriculture Food and Fisheries, London
- 25 Nabhan S.L. and Buchman G.P. (1997) Services Provided by Pollinators in Daily G eds *Nature's*
26 *Services*; Island Press, Washington
- 27 National fruit Collection (2010) <http://www.nationalfruitcollection.org.uk/> last accessed 30/06/2010
- 28 Nix J. (2010) *Farm Management Pocketbook* (41st Edition); The Andersons Centre, Melton Mowbery
- 29 Nix J. (1984) *Farm Management Pocketbook* (15th Edition); The Andersons Centre, Melton Mowbery
- 30 Ollerton J., Winfree R. and Tarrant S. (In Press) How Many Flowering Plants are Pollinated by
31 Animals?; *Oikos*
- 32 ONS (2009) Composite Price Index and annual change 1800 to 2008 (Release CDKO);
33 <http://www.statistics.gov.uk/StatBase/TSDTimezone.asp?vlnk=mm23&Pos=&ColRank=1&Rank=-1>
34 Last Accessed 30/06/10; Last Updated 09/06/2010
- 35 POST (2010) Insect Pollination *POST Note 348*; Parliamentary Office of Science and Technology;
36 London

- 1 Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O. and Kunin, W. E. (2010a) Global
2 Pollinator Declines; Trends, Impacts and Drivers; *Trends Ecol. Evol.* 25, (6), 345-353
- 3 Potts S.G., Roberts S.P.M., Dean R., Marris G., Brown M.A., Jones R., Neumann P., and Settele J.
4 (2010b) Declines of Managed Honeybees and Beekeepers in Europe; *J. Apicult. Res.* 49, (1), 15-22
- 5 Potts S.G., Woodcock B.A., Roberts S.P.M., Tscheulin T., Pilgrim E.S., Brown V.K. and Tallwin J.R.
6 (2009) Enhancing Pollinator Biodiversity in Intensive Grasslands; *J. Appl. Ecol.* 46, (2), 369-379
- 7 R project (2010) <http://www.r-project.org/>; accessed 07/01/10, last updated; 16/12/10
- 8 Rader R, Howlett B.G, Cunningham S.A, Westcott D.A, Newstrom-Lloyd L.E, Walker M.K, Teulon
9 D.A.J. and Edwards W. (2009) Alternative Pollinator Taxa are Equally Efficient but not as Effective as
10 the Honeybee in a Mass Flowering Crop; *J. Appl. Ecol.* 46, (5), 1080-1087
- 11 Scottish Government (2007) Final results of the 2007 June Agricultural Census
12 <http://www.scotland.gov.uk/Publications/2007/10/agriccensus2007>; Accessed 30/06/10, Last
13 Updated 24/10/07
- 14 Shipp J.L., Whitfield, G. H. and Papadopoulos, A. P. (1994) Effectiveness of the Bumble Bee, *Bombus-*
15 *impatiens* Cr (Hymenoptera, Apidae), as a Pollinator of Greenhouse Sweet-Pepper; *Sci Hort-*
16 *Amsterdam* 57, (1-2), 29-39
- 17 Smith K.R. (2006) Public Payments for Environmental Services From Agriculture: Precedents and
18 Possibilities; *Am. J. Agr. Econ.* 88, (5), 1167-1173
- 19 Steffan-Dewenter I. Potts S.G. and Packer L. (2005) Pollinator Diversity and Crop Pollination Services
20 are at Risk; *Trends Ecol. Evol.* 20, (12), 651-652
- 21 Stoate C., Baldi A., Beja P., Boatman N.D., Herzon I., van Doorn A., de Snoo G.R., Rakosy L. and
22 Ramwell C. (2009) Ecological Impacts of Early 21st Century Agricultural Change in Europe; *J Environ*
23 *Manage* 91 (2), 22-46
- 24 Stubbs and Drummond (2007) Conserving Native Pollinators of Blueberry: A Case Study
25 (<http://www.fao.org/ag/AGP/agps/C-CAB/Castudies/pdf/6-022.pdf>) Accessed 15/02/09
- 26 Sumner D.A. and Boriss H. (2006), Bee-economics and the Leap in Pollination Fees., *Giannini*
27 *Foundation of Agricultural Economics* 9 (3) 9-11
28 http://www.agecon.ucdavis.edu/uploads/update_articles/v9n3_3.pdf
- 29 Thomas, J. A., Telfer, M. G., Roy, D. B., Preston, C. D., Greenwood, J. J. D., Asher, J., Fox, R., Clarke, R.
30 T. and Lawton, J. H. (2004) Comparative Losses and British Butterflies, Birds and Plants and the
31 Global Extinction Crisis; *Science* 303, (5665), 1879-1881
- 32 Thomson J.D. and Goodall K. (2001) Pollen Removal and Deposition by Honeybee and Bumblebee
33 visitors to Apple and Almond Flowers; *J. Appl. Ecol.* 38, (5), 1032-1044
- 34 vanEngelsdorp D. and Meixner M.D. (2010) A Historical Review of Managed Honey Bee Populations
35 in Europe and the United States and the Factors that May Affect them; *J Invertebr Pathol* 103
36 (Special) S80-S95

- 1 Welsh Assembly Government (2008) Agricultural Small Area Statistics 2002 to 2007
2 <http://wales.gov.uk/topics/statistics/headlines/agric2009/hdw20090422/?lang=en>
- 3 Wagstaffe A. and Battey N.H. (2006) Characterisation of the Thermodormancy Response in the
4 Everbearing Strawberry 'Everest'; *J Hort Sci Biotec* 81, (6), 1086-1092
- 5 Westerkamp C. and Gottsberger G. (2000) Diversity Pays in Crop Pollination; *Crop Science* 40, (5),
6 1209-1222
- 7 Willis K.G. and Garrod G.D. (1993) Valuing Landscapes: A Contingent Valuation Approach; *J Environ*
8 *Manage* 37 (1) 1-22
- 9 Winfree R. Williams N.M., Gaines H., Ascher J.S. and Kremen C. (2008) Wild Bee Pollinators Provide
10 The Majority of Crop Visitation Across Land-Use Gradients in New Jersey and Pennsylvania; *J Appl.*
11 *Ecol.* 45, (3),793-802
- 12 Wu, J. J., Skelton-Groth, K., Boggess, W. G., Adams, R. M. (2003) Pacific Salmon Restoration: Trade-
13 offs Between Economic Efficiency and Political Acceptability; *Contemp. Econ. Policy* 21, (1), 78-89
14
- 15 Figure 1: Graphical representation of trends in insect pollinated crop area (a) and market value in the
16 UK (b) and the proportion of total UK crop area (c) and value (d) represented by these crops
17 between 1984 and 2007
- 18 Figure 2: Maximum capacity of honeybees to satisfy optimal pollination service demand ($OPC_{max,t}$) to
19 UK crops by honeybees between 1984 and 2007 at the lowest, average and upper recommended
20 hive densities (RD) per hectare.
- 21 Figure 3: Average % change in per ha yields of insect pollinated crops and all other crops in the UK
22 using 1984 as a base year