

The costs of beekeeping for pollination services in the UK? An explorative study

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1 The Costs of Beekeeping for Pollination Services in the UK – 2 an Explorative Study

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7 Summary

8 Honeybees are a key managed pollination service resource in crop agriculture, providing
9 flexible, highly generalist and resilient pollination service delivery to a broad range of UK crops.
10 Despite their potential economic impacts there is little information on the actual costs involved in
11 providing pollination services experienced by UK beekeepers. Utilising an online survey of UK
12 beekeepers, this study examines the full economic costs of providing pollination services to crops in
13 the UK, as well as examining the differences in costs experienced by different beekeepers. The
14 findings indicate that <10% of respondent beekeepers, mainly professionals, actively provide
15 pollination services to crops and rarely receive payment for this in field crops. In apple orchards,
16 where beekeepers most often receive payments, the benefits to the orchard are estimated at 86–
17 149 times the payments received by beekeepers. Although exploratory, the findings highlight the
18 need for wider collection of information on beekeeping costs and several key knowledge gaps that
19 could influence future development of the UK bee farming industry.

20 Keywords: Pollination services, Honeybees, Economics, management costs

21 Short title: Costs of Beekeeping in the UK

22 1. Introduction

23 Pollination services are a key agricultural input that influences the yield of ~75% of global
24 crops (Klein et al., 2007). In the UK, insect pollinated crops account for ~20% of planted crop area
25 and pollination services were estimated to contribute £691M to the production of these crops in
26 2011 (Vanbergen et al., 2014). Although pollination services are often primarily provided by wild
27 insect communities (Garratt et al, 2016; Garibaldi et al, 2013), in large commercial systems managed
28 pollinators, such as the European Honeybee (*Apis mellifera*), are often used to ensure stable service
29 supply by maintaining a high abundance of pollinators throughout the flowering period (Rader et al,
30 2009; Delaplane and Mayer, 2000). Furthermore, as managed insects, honeybee colonies are less
31 vulnerable to several pressures affecting wild pollinators (Winfree et al, 2010). As such, honeybees
32 can provide effective insurance in case of wild pollinator losses, and effective service provision
33 where wild pollinator populations are sub-optimal.

34 Despite the significant economic benefits of pollination services to crop growers (Garratt et
35 al., 2014, 2016), and substantial costs incurred by providing pollination services (Rucker et al., 2012),
36 evidence suggests few beekeepers are compensated for providing pollination services, limiting
37 incentives to provide hives for pollination (Carreck et al, 1997). Furthermore, the estimated capacity
38 of UK honeybee stocks to supply pollination services is only 20% of total demands (Breeze et al,
39 2014). This mismatch is confounded by continuing pressures on UK honeybee populations such as

40 pests and diseases (Wilfert et al, 2016), fluctuations in forage availability (Baude et al., 2015),
41 cumulative exposure to chemical insecticides (Godfray et al., 2014, 2015) or a combination thereof
42 (Doublet et al, 2015; Pettis et al, 2012). As a result, UK colony numbers have suffered between 10%
43 and 33% overwintering losses over the last decade, although the rate of loss has generally trended
44 downwards (BBKA, 2016).

45 Despite concerns about pollination service provision, rising honey prices and stable total
46 demand (FAO, 2016a,b; FERA, 2013), to date, the specific costs of beekeeping, particularly those
47 involved in supplying hives for pollination services in the UK, have received little research attention
48 and are routinely collected alongside other farming statistics. Understanding the costs of honeybee
49 management could provide better targeted funds to reduce the costs in beekeeping at both an
50 amateur and professional level and help develop more incentivising payment structures for
51 pollination service provision and a more profitable UK honey market. It is generally expected that
52 professional beekeepers will receive greater payments than amateurs and operate at a greater net
53 profit. Using an web-based survey, this study examines: (i) the monetary and opportunity costs of
54 providing pollination to four key insect pollinated crops (apples, strawberries, oilseed rape and field
55 beans); and, (ii) the relative monetary benefits of pollination to crop production compared to
56 payments and honey received from providing these services.

57 **2. Methods**

58 *2.1. Surveys*

59 The costs involved in beekeeping were assessed via online surveys of professional and
60 amateur beekeepers between March and September 2013. Beekeepers were sampled via beekeeper
61 association mailing lists; the Bee Farmers Association (BFA) and 237 UK local beekeeping
62 associations were approached in March 2013 and asked to invite their members to participate.
63 Reminders were sent to associations that did not explicitly reply in May and July 2013. In total 120
64 associations (51% of associations approached) responded with >75% agreeing to participate by
65 circulating the survey link. Due to the limited available population from which to draw samples, a
66 pilot study was not conducted. Questions were framed to remain as anonymous as possible and no
67 personal information was collected.

68 The survey (Appendix 1) was divided into three sections: 1) a series of questions relating to
69 the beekeeper's expertise and area of operations 2) questions relating to their general beekeeping
70 costs and honey production and 3) the costs incurred by supplying hives to provide pollination
71 services to four UK crops; apples, strawberries, oilseed rape and field beans. These crops were
72 selected due to their significance to UK crop agriculture, representing the most widespread insect
73 pollinated fruit (apples, strawberries) and arable (oilseed rape, field beans) crops in the UK (DEFRA,
74 2016a,b). For general beekeeping costs, respondents were asked to state i) the cost of equipment
75 over the last 3 years, ii) the amount spent on new queens over the last 3 years, iii) the annual costs
76 per hive of disease management, iv) the typical annual costs for controlling colony swarming and v)
77 the average monthly production of honey per hive they were able to achieve over the last 3 years.
78 The three year time span was chosen to reduce the impacts of recent years with abnormally high or
79 low costs while not alienating newer beekeepers. Crop specific costs were defined as the costs of i)
80 labour, ii) transportation, iii) the depreciation value from lost colony strength and iv) any other costs
81 particular to providing pollination service to the crop (e.g. supplemental feed required).
82 Respondents were also asked to state the amount of honey produced from each crop and their

83 estimates of depreciation (if any) in honey producing strength (as a %) from the management of the
84 hive for pollination in the crop.

85 *2.2. General beekeeping costs*

86 Costs were calculated for each respondent based on their responses to the questionnaire. In
87 order to preserve the anonymity of large beekeeping professionals, respondents were not asked to
88 state how many colonies they manage, only broad categories. As such, estimated costs per hive are
89 given based on the median number of hives in each category, taking 250 as the value for those
90 responding >200. Appendix 2 presents these estimates using the lowest and highest values form
91 each category. The value of honey production reported by each respondent was estimated using the
92 average regional price/kg reported in FERA (2011), multiplied by 4 for the number of productive
93 months in the year, as appropriate for each respondent.

94 *2.3. Costs of providing pollination services*

95 Based on their responses the economic costs incurred by each respondent (*i*) of providing
96 pollination services to each crop (*c*) were estimated as the sum of 1) the crop specific costs of
97 providing pollination services, 2) opportunity costs (*O*) of pollination compared to honey production
98 (Eq. 1), 3) the depreciation (*DP*) of the hive's honey producing strength (Eq. 2) and 4) the costs of
99 transporting hives (*T*, Eq. 3). Opportunity costs are not calculated for apples as apple flowering
100 typically occurs before the honey producing season.

$$101 \quad O_{ic} = \left(H_{ic} - \left(\frac{H_{ih}}{4} \times W_c \right) HP_r \right) \quad (Eq. 1)$$

$$102 \quad DP_{ic} = (H_{ih} \times D_{ic}) HP_r \quad (Eq. 2)$$

$$103 \quad T_{ic} = \frac{(2S_{ic} \times F)}{(P_{ic} \times N_i)} G \quad (Eq. 3)$$

104 Where H_{ic} is reported honey yield per hive in crop *c*, H_{ih} is reported average monthly honey yield
105 from placing hives outside of crop areas, W_c is the reported weeks that the hive is placed in the crop.
106 Where a hive is reported as being permanently located by a crop, the value of W_c is changed to fit
107 standard flowering durations (4 weeks in apples, 8 weeks in field beans and oilseed rape). HP_r is the
108 price per kilo of honey in region *r*, D_{ic} is the reported loss of honey producing colony strength from
109 placing the hive in crop *c*, $2S_{ic}$ is double the reported distance travelled to each crop (representing
110 pick up and collection) and F is the price per kilometre of petrol for a large van. This based on the
111 average extra urban mile per gallon of large vans registered with the Vehicle Certification Agency
112 (VCA, 2016), converted into km per litre and multiplied by the 2012 average price per litre of diesel
113 (ONS, 2014) - ~£0.17/km. P_{ic} is the proportion of respondent hives loaned or rented to a crop and N_i
114 is the lower bound number of hives that a beekeeper supplies to a crop. G is a weight parameter use
115 to prevent large numbers of colonies having unrealistically low transport costs. G has an integer
116 value of 1 for every 25 (or part thereof) hives moved to the crop, representing either multiple trips
117 or hire of larger vehicles. The relationships between different background variables (years of
118 beekeeping experience, number of beehives managed, professional or amateur status and
119 management for honey or pollination services) were explored in R with Pearson's product moment
120 correlation analysis following Shippilo-Wilks test for normality.

121 *2.4. Economic benefits of honeybee pollination*

122 To assess the relative benefits of crop pollination services from honeybees hives to apples,
123 three measures of economic benefit were estimated i) additional economic output per hive,
124 estimated by dividing the net economic benefits of pollination services per hectare of four common
125 varieties of apples (Garratt et al, 2016) by 3.6, the average recommended stocking rate of honeybee
126 colonies per hectare reported in Breeze et al (2014). This assumes that the stocking rate is adequate
127 to provide pollination services equal to current levels and that there is a linear relationship between
128 stocks and benefits. Secondly, these estimated benefits per hive were then divided by the average
129 payments per hive reported by survey respondents to produce a benefits:cost ratio for growers.
130 Finally, the benefits per hive were divided by the average net gains economic gains (fees paid +
131 honey produced) per hive reported by beekeepers.

132 **3. Results**

133 *3.1. Response*

134 In total 343 beekeepers provided usable responses, of which the majority (314; 92%) were
135 amateurs with only 8% (29) of respondents identifying as professional beekeepers. This represents
136 1.1% of beekeepers registered with the national bee unit in 2013 (FERA, 2013). Although the low
137 sample size of professionals limits statistical comparison analysis of this information some
138 differences are apparent. Notably, professionals typically had >50 hives (86%) and had been keeping
139 bees for >20 years (59%) compared to amateurs who almost always managed <20 hives (94%) and
140 usually had <5 years beekeeping experience (53%). Respondents were mainly based in South East or
141 Western England (52% in total). Many Northern and Scottish beekeeping associations felt the survey
142 was of limited interest to their members given the limited area of pollinated crops planted in these
143 regions. There were strong correlations between professionals and both years of beekeeping
144 ($r=0.35$, $p<0.001$) and number of hives ($r=0.87$, $p<0.001$) as well as years beekeeping and number of
145 beehives ($r=0.41$, $p<0.001$).

146 *3.2. Costs of Beekeeping*

147 General beekeeping costs varied strongly across respondents, with no clear relationships
148 between demographic variables. Due to the relatively small sample and high standard deviation in
149 much of the data, discussion of the results focuses on median, rather than average costs. Median
150 queen costs and swarming were both £0 indicating that most beekeepers have not experienced
151 these expenses over the last 3 years (219 and 230 respondents respectively). Among both groups of
152 beekeepers, disease management costs accounted for an average of ~62% of the estimated total
153 costs/hive. Respondents who identified as mainly managing for honey production did not report
154 higher honey yields than other respondents. Based on respondents answers, Tukey tests indicate
155 that total equipment costs are lower for the most experienced beekeepers (those with >20 years'
156 experience) compared to all other experience categories (Appendix 2, $p<0.001$). Furthermore. total
157 swarming costs are substantially higher for professionals ($f_{1,344}=31.89$, $p<0.001$) which Tukey tests
158 indicate are driven by the higher numbers of colonies (appendix 2, $p\leq0.001$). On a per-hive basis,
159 amateurs had significantly higher costs for queens than professionals ($f_{1,341}= 5.685$, $p=0.017$). This is
160 likely to be an effect of beekeeping experience, which Tukey tests indicate are significantly lower for
beekeepers with >20 years' experience compared to those with 6-10 years ($t= -3.045$, $p= 0.0199$),

162 and ≤5 years' experience ($t = -2.738$, $p=0.047$). Comparing the total costs of queens reported by
 163 respondents, there are only significant differences between the most experienced (>20 years)
 164 beekeepers and those who have 6-10 years beekeeping experience ($t = 3.063$, $p=0.017$), while by
 165 contrast the number of hives a beekeeper manages did not significantly affect their queen costs.
 166 Honey production per hive was only significantly greater between the most and least experienced
 167 beekeepers ($t=7.3565$, $p=0.023$). In total, median annual costs were estimated at £27.00/hive,
 168 although this falls by ~57% to £11.87/hive once the annual value of honey is considered.

169 **Table 1** Detailed breakdown of annual costs per hive for professional and amateur beekeepers

	Amateur (n=314)			Professional (n=29)			All (n=343)		
	Average	S.D.	Median	Average	S.D.	Median	Average	S.D.	Median
Queens	£0.27	£0.55	£0.00	£0.03	£0.05	£0.01	£0.25	£0.53	£0.00
Equipment	£12.38	£18.67	£6.67	£10.30	£18.03	£2.22	£12.20	£18.60	£6.67
Swarming	£2.55	£8.13	£0.00	£5.89	£16.52	£0.02	£2.84	£9.15	£0.00
Disease	£23.32	£23.28	£15.00	£17.93	£17.16	£10.00	£22.87	£22.85	£15.00
Total	£38.53	£34.75	£27.00	£34.16	£30.58	£20.48	£38.16	£34.40	£27.00
Honey/month (kg)	2.87	3.28	1.81	2.74	3.01	2.00	2.86	3.25	1.81
Honey value (£)	£23.21	£26.64	£15.47	£21.53	£23.54	£17.06	£23.07	£26.37	£15.47
Net costs	£15.32	£43.41	£13.16	£15.32	£43.41	£13.16	£12.63	£44.91	£5.81

170 Key Queens, equipment, swarming = one third of the reported three year costs of queens, beekeeping equipment and controlling for
 171 swarming divided by the estimated number of hives per beekeeper. Disease = the reported annual costs per hive of controlling for
 172 diseases and parasites. Total = the total costs per hive per year. Honey/month = the reported average honey produced per month from
 173 each hive over the last 3 years (in Kg). Honey value = 4 times the average monthly honey production multiplied by the costs/kg of honey
 174 from FERA (2013). Net costs = total costs – honey value. For the purpose of comparison, respondents that did not report honey harvested
 175 are assumed to have a value of 0.

176 3.3. Pollination Service Provision

177 Among both professional and amateur beekeepers, the majority (62%) reported they
 178 primarily kept bees for honey production while only 5% kept hives for pollination services. Of the
 179 professional respondents, 27% reported they either primarily provided bees for pollination services
 180 or varied their activities between years. Respondents also reported providing pollination services to
 181 a range of other crops including glasshouse vegetable seed production and a range of tree and small
 182 fruit crops. No further analysis was conducted for strawberries due to the low number of
 183 respondents (n=6) that rented or loaned hives to provide pollination services to this crop.

184 The greatest median crop specific management costs were reported in apples (£5/hive)
 185 compared to £3.5/hive for oilseed rape and £0/hive for field beans, although there was substantial
 186 variation among these costs (Table 2). Only three amateur beekeepers reported payments for their
 187 pollination services while 20 professionals received varying levels of payment. Beekeepers who
 188 rented or loaned their hives to crops were more likely to receive payments for providing pollination
 189 services to apples (57% of those providing services, median £50/hive) than oilseed rape (11% of
 190 those providing services, median £25/hive) and field beans (14% of those providing services, median
 191 £32/hive). In apples there were also strong correlations between payments received and
 192 transportation costs ($r=0.41$, $p=0.021$), however no other cost component correlated with payments
 193 in any crops.

194 Very few beekeepers reported any loss of honey producing colony strength (median 0% for
 195 all three crops) with only 20%, 7% and 6% reporting any depreciation in honey producing strength.
 196 Median estimated weekly honey production per hive was typically lower in crops (apples: 0.09kg,
 197 oilseed rape: 0.51kg/week, field beans: 0.43kg/week) than non-crop habitat reported by the same

198 beekeepers (median 1.15kg/week). However, as little honey production is possible in the early parts
 199 of the season and apples themselves produce only small quantities of low sugar nectar, this likely
 200 represents only a few small, non-crop nectar sources available at this time of year. Beekeepers
 201 generally travelled further to apple orchards (median 11.5km) resulting in substantially higher
 202 transport costs.

203 **Table 2** Detailed breakdown of annual costs per hive for professional and amateur beekeepers

	Apples (n=30)			Oilseed Rape (n=46)			Field Beans (n=35)		
	Average	S.D.	Median	Average	S.D.	Median	Average	S.D.	Median
Crop-Specific	£7.47	£9.05	£5.00	£12.59	£15.99	£3.50	£7.69	£13.55	£0.00
Depreciation	£0.26	£0.69	£0.00	£0.12	£0.5	£0.00	£0.03	£0.13	£0.00
Labour	£3.47*	£10.44*	£0.00*	£1.05	£6.08	£0.00	£0.68	£3.80	£0.00
Transport	£1.34	£2.27	£0.48	£0.51	£1.28	£0.14	£0.46	£1.18	£0.17
Total	£12.64	£15.11	£8.31	£13.98	£16.68	£6.89	£8.64	£14.93	£0.73
Honey/week (kg)	0.74	1.27	0.09	0.74	0.70	0.51	0.67	0.77	0.43
Honey value (£)	£8.90	£18.35	£0.58	£9.66	£10.92	£4.48	£8.93	£12.32	£3.10
Weeks supplied	5.48	5.51	4.00	6.37	3.37	5.00	5.77	3.78	4.00
Opportunity	NA	NA	NA	-£1.01	£11.71	£0	-£2.79	£10.97	-£0.17
Payment**	£27.03	£27.6	£27.5	£2.96	£10.6	£0	£4.9	£12.98	£0
Net costs	-£14.50	£30.53	-£11.82	£10.02	£23.73	£9.61	£0.93	£20.56	£0.00

204 Key Total costs = the total costs incurred before accounting for honey and payment. Opportunity = the difference in the
 205 value of honey produced from the crop and the value of honey potentially produced from areas outside of crop fields;
 206 negative values indicate that honey production is greater in the crop than areas outside of crop fields. Payments = the
 207 value of payments received for providing hives. Net costs = the final costs of supplying each hive after accounting for honey
 208 production (opportunity) and payments received (total costs + opportunity - payments). * a single respondent was
 209 excluded from the assessment of labour costs as an extreme outlier. ** It was assumed that beekeepers who responded
 210 with NA or left no answer received no payment.

211 3.4. Benefit ratios in apple production

212 Using an estimate of 3.6 hives/ha to provide optimal pollination services and measures
 213 (Breeze et al., 2014) of the net economic benefits of pollination services to four apple varieties in
 214 2012 (Garratt et al., 2016), each hive was estimated to provide between £2,361 and £4,111 of
 215 additional net output per hectare to four varieties apples (Table 3). Compared with the median
 216 payments reported by respondents (£27.50), this results in between £86-£149 of pollination service
 217 benefits per £1 spent on hive rental, depending on the variety of apple.

218 **Table 3** Apple producer gross benefits from optimal honeybee pollination services

	Pollination Benefits (£000/ha)	Benefits/hive (£/ha)	Benefits:costs (£/hive)
Cox	£11.9	£3308.9	£120.23
Gala	£14.8	£4101.9	£149.16
Braeburn	£8.5	£2368.3	£86.12
Bramley	£14.5	£4018.9	£146.41

219 Key: Benefits/hive = the gross value of additional pollination services per hectare of each apple cultivar provided by a single
 220 hive. Benefits:costs = the gross value of pollination services provided per hectare of each cultivar per £1 paid to beekeepers
 221 (median payments in Table 2: £22.5).

222

223

224 **4. Discussion**

225 **4.1. Basic Management costs**

226 Using an online survey of UK beekeepers this study examined the general costs of
227 beekeeping and the specific costs of providing pollination services to three major UK crops (apples,
228 oilseed rape and field beans) for both professional and amateur beekeepers. The findings indicate
229 that a majority (62%) of beekeeper expense on managing hives comes from pest and disease
230 management. This is likely due to *Varroa destructor*, a parasitic mite that has become near
231 ubiquitous across the UK and acts as a viral vector (Potts et al., 2010; Wilfert et al., 2016), which
232 several respondents stated as being a significant pressure on their beekeeping activities. Presently,
233 the UK government supports honeybee health through the National Bee Unit who actively monitor
234 the spread of notifiable pests and diseases in the UK and remains committed to improving and
235 maintaining this through the recent National Pollinator Strategy (DEFRA, 2014), leading to the
236 development of disease surveillance network (DEFRA, 2015). However, many treatments for *Varroa*
237 available within Europe are of limited availability in the UK, requiring a special medical request to be
238 made via a veterinarian in order to be imported from the EU (VMD, 2013). With the recent decision
239 of the UK to withdraw from the EU, changes to these regulations will be required which may
240 facilitate greater access to effective treatments, however further work is required to determine the
241 impacts on beekeeper costs. As historic declines in colonies have been attributed to rising costs
242 reducing the number of professional beekeepers (Potts et al, 2010) and potentially acting as a
243 barrier to amateurs maintaining larger colony numbers. The findings of this study suggest that
244 continued investment and support for honeybee health could significantly reduce the burden of
245 diseases on UK beekeeping. Professional and highly experienced beekeepers had significantly lower
246 equipment costs than other beekeepers, possibly reflecting bulk purchases and the accumulation of
247 equipment over time respectively. However, there was no significant difference in the amount of
248 honey produced per hive by amateur and professional beekeepers. Furthermore, most respondents
249 had no queen or swarming costs, indicating that these costs are infrequent spikes, possibly more
250 infrequent than the 3 year time span captured by this survey. Although the findings of this study are
251 based on reasonable assumptions, more precise information on the number of hives would allow for
252 more refined assessment of these general costs of beekeeping, particularly for amateurs.

253 **4.2. Costs for pollination services provision**

254 The specific costs of managing honeybee colonies for pollination services are often relatively
255 small, mostly stemming from crop specific management costs in apples and oilseed rape, although a
256 few larger scale professional beekeepers reported very high labour costs. In contrast with findings by
257 Rucker et al (2012) transportation costs are relatively small, probably due to the shorter distances
258 travelled by UK migratory beekeepers, and few beekeepers report any loss of colony strength, even
259 in apple, a low nectar crop. Similarly, although past studies (Godfray et al., 2014, 2015) have
260 suggested that systemic insecticides may have an impact on honeybee colony health, the very low
261 number of beekeepers reporting any depreciation from oilseed rape or field beans, supports the
262 findings by Rundlof et al, (2015) that field level exposure has no detectable impact on colony health.
263 However, as this study was undertaken before the current restrictions on neonicotinoids, it is
264 possible that perceptions of neonicotinoid impacts on colonies may have changed since.

265 There are also notable opportunity costs in supplying hives for oilseed rape, despite it's

266 relatively high nectar availability. However, as honey production varies throughout the year, it is
267 possible that the honey produced during the early oilseed rape flowering season may be in a below
268 average production month, resulting in costs being overestimated. By contrast, depreciation of
269 honey producing strength was not considered to be a substantial factor by most respondents, even
270 in apples which are often considered poor nectar sources (Free, 1993). Although informative, these
271 results would benefit from a more detailed and systematic examination of the specific costs of
272 beekeeping for pollination, such as the costs of vehicular hire, any variation in payments received
273 from growers of different scales and the value of honey sales contracts.

274 4.3. Benefits of pollination services

275 Comparing the costs of providing pollination services with the benefits received by apple
276 orchards highlights that the payments typically received 86-149 times smaller than the monetary
277 benefits of the pollination services provided. Although based on observed field data, it is likely that
278 successive hives will provide diminishing marginal benefits (Garratt et al., 2016). Furthermore there
279 is considerable uncertainty within the literature regarding the recommended stocking rates, due to
280 differences in stocking rates, system inputs and estimation methods (Breeze et al., 2014) as well as
281 varietal differences in polliniser compatibility (Matsumoto et al., 2007) and floral morphology (Free,
282 1993). As such, the findings indicate that a better understanding of the relationship between
283 honeybee stocking rates and pollination services could lead to the development of pricing schemes
284 for professional pollination services that better reflect the benefits of pollination services.

285 4.4. Broader Implications

286 Although exploratory, the findings of this study highlight three future avenues for further
287 research, development of pollination service markets, and policy support into the economics of UK
288 beekeeping. Foremost, the results indicate that few amateurs provide pollination services to crops,
289 despite most amateurs being located in crop heavy regions of England. Understanding both the finer
290 costs of providing services and the motivations for doing so among these amateurs may allow policy
291 to create more opportunities for amateur beekeepers to supply hives to local farmers, particularly
292 smaller enterprises. As of 2010, the UK has only 20% of the honeybee hives required to provide
293 optimal pollination services, despite the growing demands for pollination services from oilseed rape
294 and field beans (Breeze et al., 2014). While many producers rely upon wild pollinators to provide
295 the majority of their service needs (Garratt et al., 2016), the use of managed honeybees could be
296 effective at reducing yield gaps if wild pollination services are insufficient to provide maximum
297 output, as observed in gala apples (Garratt et al., 2014). However, some caution should also be
298 exercised to avoid over-pollination where wild pollinators are already adequate, possibly resulting in
299 producer losses (e.g. cox apples, Garratt et al., 2014) and benefits are likely to be much smaller in
300 lower priced arable crops (e.g. Bommarco et al., 2012). Stronger monitoring of pollinator
301 populations (e.g. Carvell et al., 2016) and sedentary honeybee hives could therefore facilitate bee
302 farmers adopting a more demand (based on likely services shortfalls; e.g. Polce et al., 2014) and
303 benefit (based on output gains) driven based pricing scheme that more accurately reflects the value
304 of managed pollination services.

305 Secondly, the findings indicate that some beekeepers, including professionals, are providing
306 pollination services at a net loss and that few beekeepers are able to extract quantities of honey
307 comparable to non-crop habitats. Although possibly in part a reflection of the assumptions made in

308 the survey, the findings nonetheless highlight the importance of payments to offset the potential
309 limitation in honey harvest, a key driver in pollination service prices in the USA (Rucker et al., 2012).
310 Further research into farmer willingness to pay for pollination services, particularly from arable
311 farmers, whose large fields are unlikely to receive adequate pollination from semi-natural habitat
312 alone (Rader et al., 2009; Garibaldi et al., 2011), has the potential to incentivise better payments for
313 pollination services outside of arable crops. However, this may be complicated by the relatively
314 limited impact of pollination services on productivity in these crops (e.g. Bommarco et al., 2012).

315 Finally: the necessity of using a questionnaire element is due largely to the lack of data
316 collection on bee farming as an agricultural sector. Although the results demonstrate that amateur
317 beekeepers do provide pollination services and experience costs in doing so, most beekeepers
318 providing services were professionals that often supplied larger numbers of hives. Unlike other
319 farming sectors in the UK however (e.g. DEFRA, 2016, FBS, 2016), there is no systematic collection of
320 enterprise data for bee farming. Systematically measuring the costs and business performance of the
321 small number of professional beekeepers in the UK as with other farming sectors would therefore
322 give an insight into the financial factors affecting both the UK's honey market and a majority of the
323 pollination service market.

324 **References**

- 325 Baude M., Kunin W.E., Boatman N., Conyers S., Davies N., Gillespie M.K.A., Morton R.D., Smart S.M.
326 and Memmott J. (2015) Historical nectar assessment reveals the fall and rise of floral resources in
327 Britain; *Nature* 530, 85-88
- 328 Breeze T.D., Vaissiere B., Bommarco R., Petanidou T., Seraphides N., Kozák L., Scheper J., Biesmeijer
329 J.C., Kleijn D., Gyldenkærne S., Moretti. M., Holzscuh A., Steffan-Dewenter I., Stout J., Pärtel M.,
330 Zobel M. and Potts S.G. (2014) Agricultural Policies Exacerbate Honeybee Pollination Service Supply-
331 Demand Mismatches Across Europe; *PLoS One* 9, e82996 DOI: 10.1371/journal.pone.0082996
- 332 Bommarco R., Marini L. and Vaissiere B. (2012) Insect pollination enhances seed yield, quality, and
333 market value in oilseed rape; *Oecologica* 169, 1025-1032
- 334 British Beekeepers Association (BBKA) (2016) *Winter Survival Survey* (Press Release, original
335 document not publicly accessible)
336 [http://www.bbka.org.uk/files/pressreleases/winter_survival_release_2016_\(2\)_1469182251.docx](http://www.bbka.org.uk/files/pressreleases/winter_survival_release_2016_(2)_1469182251.docx)
337 published 21/07/16
- 338 Carreck N.L., Williams I.H. and Little D.J. (1997) The Movement of honey bee colonies for crop
339 pollination and honey production by beekeepers in Great Britain; *Bee World* 78, 67-77
- 340 Carvell et al., (including Breeze T.D.) (2016) Design and Testing of a National Pollinator and
341 Pollination Monitoring Framework
342 <http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=2&ProjectID=19259>
- 344 Delaplane K.S. and Mayer D.E. (2000) *Crop Pollination by Bees*, CABI Publishing; Wallingford.

- 345 DEFRA (2016a) *Agriculture in the United Kingdom 2016*: Chapter 7 - Crops
346 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/205362/auk-chapter07-06jun13.xls last updated 26/05/16
- 348 DEFRA (2016b) Horticulture Statistics 2015 <https://www.gov.uk/government/statistics/horticulture-statistics-2015> last updated 22/07/16
- 350 DEFRA (2016c) Structure of the agricultural industry in England and the UK at June
351 <https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june> Last updated 20/12/16
- 353 DEFRA (2015) National Pollinator Strategy: Implementation Plan
354 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/474386/nps-implementation-plan.pdf
- 356 DEFRA (2014) The National Pollinator Strategy: for bees and other pollinators in England
357 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/409431/pb14221-national-pollinators-strategy.pdf
- 359 Doublet V., Labarussias M., de Miranda J.R., Moritz R. and Paxton R. (2015) Bees under stress:
360 sublethal doses of a neonicotinoids pesticide and pathogens interact to elevate honey bee mortality
361 across the life cycle; *Environmental Microbiology* 17, 969-983
- 362 Farm business Survey (2016) *Farm Business Survey Data builder*,
363 <http://www.farmbusinesssurvey.co.uk/DataBuilder/>
- 364 FAO (2017a) *Production - Livestock Primary* <http://www.fao.org/faostat/en/#data/QL> last updated
365 13/02/17
- 366 FAO (2017b) *Prices - Livestock Primary* http://faostat3.fao.org/faostat-gateway/go/to/download/P/*/E, accessed 20/08/14
- 368 FERA (2013) *South East Region Honey Survey 2013*
369 <https://secure.fera.defra.gov.uk/beebase/downloadDocument.cfm?id=911> accessed 20/08/14
- 370 FERA (2011) *South East Region Honey Survey 2011*
371 <https://secure.fera.defra.gov.uk/beebase/downloadDocument.cfm?id=582> accessed 20/08/14
- 372 Free J (1993) *Crop Pollination by Insects* (2nd Edition), Academic Press, London.
- 373 Garibaldi L.A. et al (2011) Stability of pollination services decreases with isolation from natural areas
374 despite honey bee visits; *Ecology Letters* 14, 1062-1072
- 375 Garibaldi L.A. et al (2013) Wild pollinators enhance fruit set of crops regardless of honey-bee
376 abundance; *Science* 339, 1608-1611
- 377 Garratt M.P., Breeze T.D., Jenner N., Polce C., Biesmeijer J.C and Potts S.G. (2014) Avoiding a bad
378 apple: insect pollination enhances fruit quality and economic value; *Agriculture, Ecosystems and
379 Environment* 184, 34-40

- 380 Garratt M.P., Breeze T.D., Boreaux V., Fountain M.T., McKerchar M., Webber S.M., Coston D.J.,
381 Jenner N., Dean R., Biesmeijer J.C and Potts S.G. (2016) Apple pollination: Demand depends on
382 cultivar and supply depends on pollinator identity; *PLoS* 11(5): e0153889.
- 383 Godfray H.C.J., Blacquiere T., Field L.M., Hails R.S., Pterowfsky G., Potts S.G., Raine N.E., Vanbergen
384 A.J. and McLean A.R. (2014) A Restatement of the Evidence Base Concerning Neonicotinoid
385 Insecticides and Insect Pollinators; *Proceedings of the Royal Society B – Biological Sciences* 281,
386 20140558
- 387 Godfray H.C.J., Blacquiere T., Field L.M., Hails R.S., Potts S.G., Raine N.E., Vanbergen A.J. and McLean
388 A.R. (2015) A Restatement of Recent Advances in the Natural Science Evidence Base Concerning
389 Neonicotinoid Insecticides and Insect Pollinators; *Proceedings of the Royal Society B – Biological
390 Sciences* 282, 20151821
- 391 Klein A.M., Vaissière B.E., Cane J.H., Steffan-Dewenter I., Cunningham S.A. et al (2007) Importance of
392 Pollinators in Changing Landscapes for World Crops; *Proceedings of the Royal Society of London B –
393 Biological Sciences* 274, 303-313.
- 394 Matsumoto S., Eguchi T., Bessho H. and Abe K. (2007) Determination and Confirmation of S-Rnase
395 Genotypes of Apple Pollinators and Cultivars; *Journal of Horticultural Science and Biotechnology* 82,
396 (2), 323-329
- 397 Office of National Statistics (2014) Weekly Fuel prices <https://www.gov.uk/government/statistical-data-sets/oil-and-petroleum-products-weekly-statistics> accessed 20/08/14, last updated 07/05/14
- 398
- 399 Pettis J.S., vanEngelsdorp D., Johnson J. and Dively G. (2012) Pesticide exposure in honey bees
400 results in increased levels of the gut pathogen Nosema; *Naturwissenschaften* 99, 153–158
- 401 Polce C., Termansen M., Aguirre-Gutierrez J., Boatman N.D., Budge G.E., Crowe A., Garratt M.P.,
402 Pietravalle S., Potts S.G., Ramirez J.G., Somerwill K.G. and Biesmeijer J.C., (2014) Species Distribution
403 Models for Crop Pollination: A Modelling Framework Applied to Great Britain; *PLoS One* 8, e76308
- 404 Potts S.G., Roberts S.P.M., Dean R., Marrs G. and Brown M.A. et al (2010) Declines of managed
405 honeybees and beekeepers in Europe; *Journal of Apicultural Research* 49, 15-22.
- 406 Rader R., Howlett B.G., Cunningham S.A., Westcott D.A. and Newstrom-Lloyd L.E. et al (2009)
407 Alternative Pollinator Taxa are Equally Efficient but not as Effective as the Honeybee in a Mass
408 Flowering Crop; *Journal of Applied Ecology* 46, 1080-1087
- 409 Rundlof M., Andersson G.K.S., Bommarco R., Fries I., Hederstrom V., Herbertsson L., Jonsson O., Klatt
410 B.K., Pedersen T.R., Yourstone J. and Smith H.G. (2015) Seed coating with a neonicotinoid insecticide
411 negatively affects wild bees; *Nature* 521, 77-80
- 412 Rucker R.R., Thruman W.H. and Burgett M. (2012) Honeybee pollination markets and the
413 internalisation of reciprocal benefits; *American Journal of Agricultural Economics* 94, 956–977
- 414 Vanbergen A., Heard M.S., Breeze T.D., Potts S.G. and Hanley N. (2014) Status and Value of
415 Pollinators and Pollination Services – A report to the Department of Environment Food and Rural
416 Affairs (DEFRA) <https://consult.defra.gov.uk/plant-and-bee-health-policy/a-consultation-on-the->

417 [national-pollinator-](#)
418 [strategy/supporting_documents/140314%20STATUS%20AND%20VALUE%20OF%20POLLINATORS%2](#)
419 [0AND%20POLLINATION%20SERVICES_FINALver2.pdf](#)

420 VCA (2016) *Van CO₂ and Fuel Consumption database* <http://vanfueldata.dft.gov.uk/vehicles.aspx> ,
421 last updated 25/10/16

422 Veterinary Medicines Directorate (2013) *Action Plan on the Availability of Medicines for Bees*;
423 http://www.vmd.defra.gov.uk/pdf/bee_actionplan.pdf last accessed 20/08/14, last updated
424 01/08/13

425 Wilfert L., Long G., Leggett H.C., Schmid-Hempel P., Butlin R., Martin S.J.M. and Boots M (2016)
426 Deformed wing virus is a recent global epidemic in honeybees driven by Varroa mites; *Science* 351,
427 594-597

428 Winfree R, Aguilar R, Vazquez DP, LeBuhn G and Aizen M (2010) A meta-analysis of bees' responses
429 to anthropogenic disturbance; *Ecology* 90, 2068-2076.

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