Assessing the impact of increased maize cropping on pollinators

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INTRODUCTION

Maize is increasingly being grown as a feedstock for anaerobic digestion (AD) biogas production, accounting for 29,373 hectares in England (17% of the total maize area) in 2014 (Defra, 2014). Between 2010 and 2013 the area cropped with maize in Lincolnshire increased by 99% and in North and North East Lincolnshire by 726% (Defra, 2013) and the figures are anticipated to have continued to rise although there are indications this may now be starting to plateau (Nicholson, 2016). This increase has inevitably impacted upon crop rotation in arable systems although there is limited evidence at present to indicate particular displacement patterns. Some research has suggested that winter wheat is less likely to be displaced by maize for AD (Defra/ADAS: 2015) however other studies have highlighted the potential of maize as a break crop in rotations of wheat and oilseed rape citing both environmental and profitable benefits for UK farming including its assistance in blackgrass control (Vogel and Hellawell, 2011). Anecdotal evidence in Greater Lincolnshire suggests that blackgrass control in addition to low wheat prices and a requirement for more spring cropping options may be driving displacement by maize.

Insect pollinators are responsible for an estimated 35% of world food production (Klein et al., 2007) and believed to be worth more than £430 million in the UK alone (Breeze et al*.,* 2011). The area of insect pollinated crops in the UK represented 20.4% of UK cropland in 2007 and has been growing at an average rate of 21,250ha per year (Breeze et al., 2011). Wild and domesticated bees are well documented as effective crop pollinators however the contributions of non-bee pollinators have been less widely explored (Rader et al., 2016). Flower visitor assemblages may include a variety of other insects such as flies, butterflies, moths, beetles and wasps. While bees are widely perceived as of most importance, flies are considered to be the second most important insect order for both flower visiting and pollination (Larson et al., 2001). By contrast however there is little evidence to support the presumption that in the UK butterflies and moths deliver pollination services to insect-pollinated crops (Vanbergen et al., 2014).

Pollinator decline is well documented but is difficult to determine accurately because of a lack of standardised abundance monitoring for the majority of taxa (Vanbergen et al., 2014). British records of wild bees (bumblebees and solitary bees) before and after 1980 revealed species richness to have declined by 29% with hoverflies declining by 29% also (Biesmeijer et al., 2006). A 54% fall in overall honeybee hive numbers was recorded in England between 1985 and 2005 (Potts et al., 2010) while butterflies and moths have also generally declined in abundance and species distributions (Vanbergen et al., 2014).

Habitat loss and fragmentation are key factors in the decline of pollinator numbers. Agricultural intensification has led to a more homogenised landscape characterised by large crop fields with fewer non-cultivated habitats to provide floral resources and nesting sites for wild bees (Nicholls and Altieri, 2013). Crop monocultures often result in large areas of temporary pollinator forage, flowering for only a few weeks at a time (Altieri et al., 2015), making the number and diversity of habitats in the surrounding landscape of great importance (Kennedy et al., 2013). Studies have found that cultivated arable fields surrounded by other monocultures have significantly fewer bees than crops surrounded by uncultivated semi-natural habitats and the number of bumblebees on crops increases with proximity to natural habitats (Ockinger and Smith, 2007). Furthermore, impacts may vary for different species of bumblebee depending on their foraging radius from the nest (Walther-Hellwig and Frankl, 2000). For example, the foraging distance of *Bombus terrestris* and *Bombus lapidarius* has been found to be far greater than that of *Bombus muscorum* and may therefore result in potential pollinator limitation at a landscape scale. By contrast, less sophisticated flower visitors, such as many flies, beetles, butterflies and moths, may be less reliant on habitat diversity as a result of their more random approach to forage (Richards, 2001).

Certain crops have different requirements from insect pollinators and may need species with particular traits; for example long-tongued bees acting as effective pollinators of field beans. Studies on UK farms have shown that bumblebees are the primary visiting and pollinating insect of field beans making up 88.4% of visits, however oilseed rape was found to be more generalised being pollinated by many different insects with bumblebees, honeybees, solitary bees and hoverflies together making up just 35.3% (Garratt, 2013). Across the world, the managed honeybee is used to enhance crop pollination (Kennedy et al., 2013) however the importance of these domesticated pollinators over wild pollination services is the subject of much debate and on a global level, evidence is emerging that wild bees and other insects are actually more important to crop pollination than honeybees (Garibaldi et al, 2013). Previously 80% of global agricultural pollination services were attributed to the domesticated European honeybee *Apis mellifera* (Carreck and Williams, 1998) but growing research suggests the importance of wild pollinators may have been underestimated. Analysis of honeybee hive numbers indicates that their pollination capacity fell from 70% in 1984 to just 34% in 2007 (Breeze et al., 2011). In spite of this decline, insect pollinated crop yields have risen by an average of 54% since 1984, casting doubt on theories that honeybees provide the majority of pollination services. Additionally, studies of crop flower visitation by honeybees to oilseed rape found that the likelihood of pollen transfer between insect bodies and the plant's stigma was just 34% compared with 71.3% for solitary bees (Woodcock et al., 2013).

Studies to determine the effectiveness of bee versus non-bee pollinators have found that on average the amount of pollen deposited per visit to crop flowers is lower for non-bees than for bees. However, the high visitation frequency of non-bees to crop flowers compensates for the deficit in per-visit effectiveness and results in high pollination services overall (Rader et al, 2016). Further caged studies of individual pollinator species – red mason bee (*Osmia rufa)* and two hoverfly species (*Eristalis tenax* and *Episyrphus balteatus*) on oilseed rape found hoverflies required approximately five-fold densities of the red mason bees to reach a similar fruit set and yield (Jauker et al., 2012).

Understanding how insects use arable crops extends beyond just pollination however. Studies have found that aphidophagous (aphid feeding) species of hoverfly preferentially overwinter within fields of oilseed rape and winter wheat and that there is a strong negative correlation between the abundance of overwintering hoverflies and the abundance of aphids in the spring, which also suggests a biological control function by the hoverflies in autumn (Raymond et al., 2014).

This study undertook to consider whether increased maize cropping is having an impact on insect pollinators. The research sought to understand how a range of invertebrates, with the potential to act as pollinators, use a range of common arable crops. This will provide an evidence base upon which future work could build to enhance pollinator resource within the farmed landscape and raise awareness of their importance to arable businesses.

METHODS

Study sites

Field surveys were carried out in the spring/summer of 2016 on four arable crop types: *Zea mays* (maize), *Triticum aestivum* (winter wheat), *Brassica napus* (oilseed rape) and *Pisum sativum* (peas) of which three were marrowfat and two were vining peas. These were chosen based on both crop availability and to provide a range of insect, wind and self-pollinated crops for comparison. A total of five fields of each crop type were selected across five participating landholdings in Lincolnshire and each field surveyed once between 23 May and 10 June and again between 14 June and 17 July giving a total of 40 samples. Each survey site was separated by at least one field. The two time periods were chosen to take into account variations in growth stages of the crops being surveyed, together with different emergence dates for insect pollinators in order to gather as much data as possible within the confines of the pilot study.

Where possible, consistency of crop variety was maintained across the survey sites although this was restricted in part by those being grown by participating farms. Survey sites were also selected with unmanaged or grass margins, where possible avoiding those where pollen and nectar mixes had been sown as these are designed to benefit pollinating insects and could have impacted on the results.

The surrounding crop types within a 500m buffer of the survey site were mapped and a desktop exercise was undertaken to identify non-arable habitats present such as woodland or urban areas to enable surrounding land use to be taken into account when analysing the results.

Finally, notes were taken regarding the date and number of insecticide applications as this could also potentially affect the results of the pollinator surveys.

Pollinator surveys

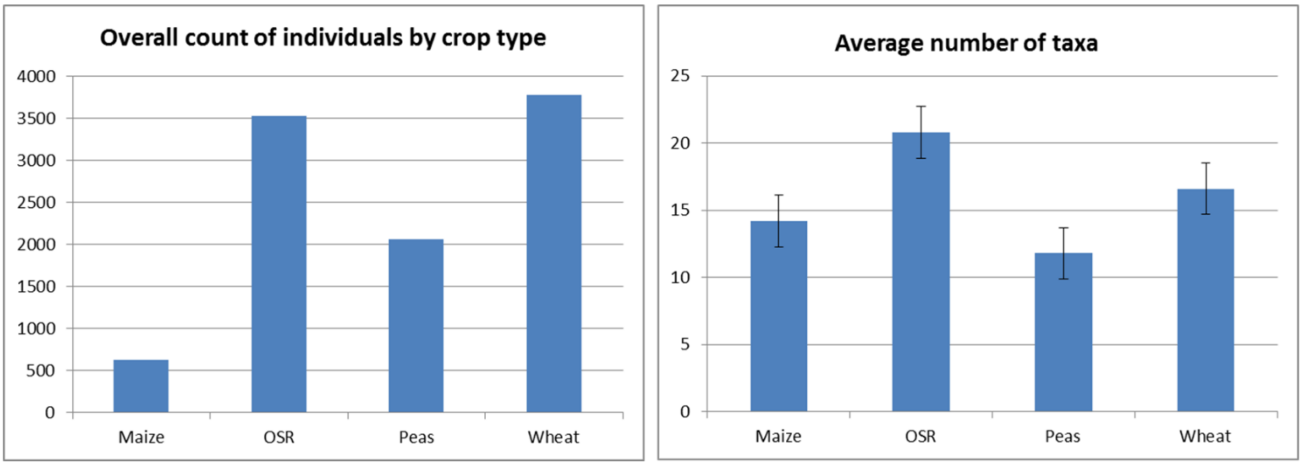
Pollinator surveys were undertaken by a single surveyor who was an experienced pollinator specialist. In each crop field, two 30 minute transects were walked along tramlines, at least 10 metres in from the field margin and species seen within two metres on either side of the tramlines were recorded.

The spring of 2016 was quite cold and so where possible surveys took place between 10am and 4pm in dry, mild conditions with shade temperatures over 17°C irrespective of sunshine or between 13°C and 17°C if at least 60% of the walk was in sunshine (Pollard and Yates, 1993) however there were some cases where surveys had to be undertaken if the temperature was over 14°C. For the purposes of this study, any insect visiting the crop was considered as a potential pollinator and records of the following were therefore made: bumblebees, honey bees, solitary/mining bees, mason/leafcutter bees, moths, butterflies, flies, beetles and other insects. Where time allowed, pollinators were identified to species level.

Analysis

Transect data for each visit was averaged and data from the first and second visit period was then combined. For the purposes of a robust analysis, a total of 37 groups, or taxa, were considered and this consisted of individual species, combined species (e.g. where single records of several species from the same family could be considered together) and families. The number of insecticide applications was summed to give a value between 0 and 3. Data for all analyses was transformed (log n+1) and for redundancy analysis (RDA) data was Hellinger transformed to allow for large numbers of absent taxon groups in some fields. Variables were added to the RDA in the order cultivated land, crop type, temperature and finally insecticide. Statistical analysis was then undertaken using the *vegan* package in R to test for significance.

RESULTS



Figs. 1a and 1b: Summary statistics show that lowest overall numbers of individuals were recorded in maize but that peas supported lower overall numbers of taxa. By contrast winter wheat contained the highest overall numbers of individuals while number of taxa were highest in oilseed rape.

More than 10,000 individual invertebrates were recorded during the course of the fieldwork, including a large number of blossom beetles which occurred in their hundreds at some of the sample sites making them difficult to quantify. It is interesting to note that of these thousands of individuals, bumblebees, honeybees and mining bees accounted for only 41 specimens. Initial summary data for the four surveyed crop types shows that the lowest counts of invertebrates were recorded in maize by a large margin while winter wheat supported the highest numbers **(Fig. 1a).** The average taxon richness by crop type however showed peas (marrowfat and vining combined) to contain the fewest numbers while oilseed rape recorded the most **(Fig. 1b)**.

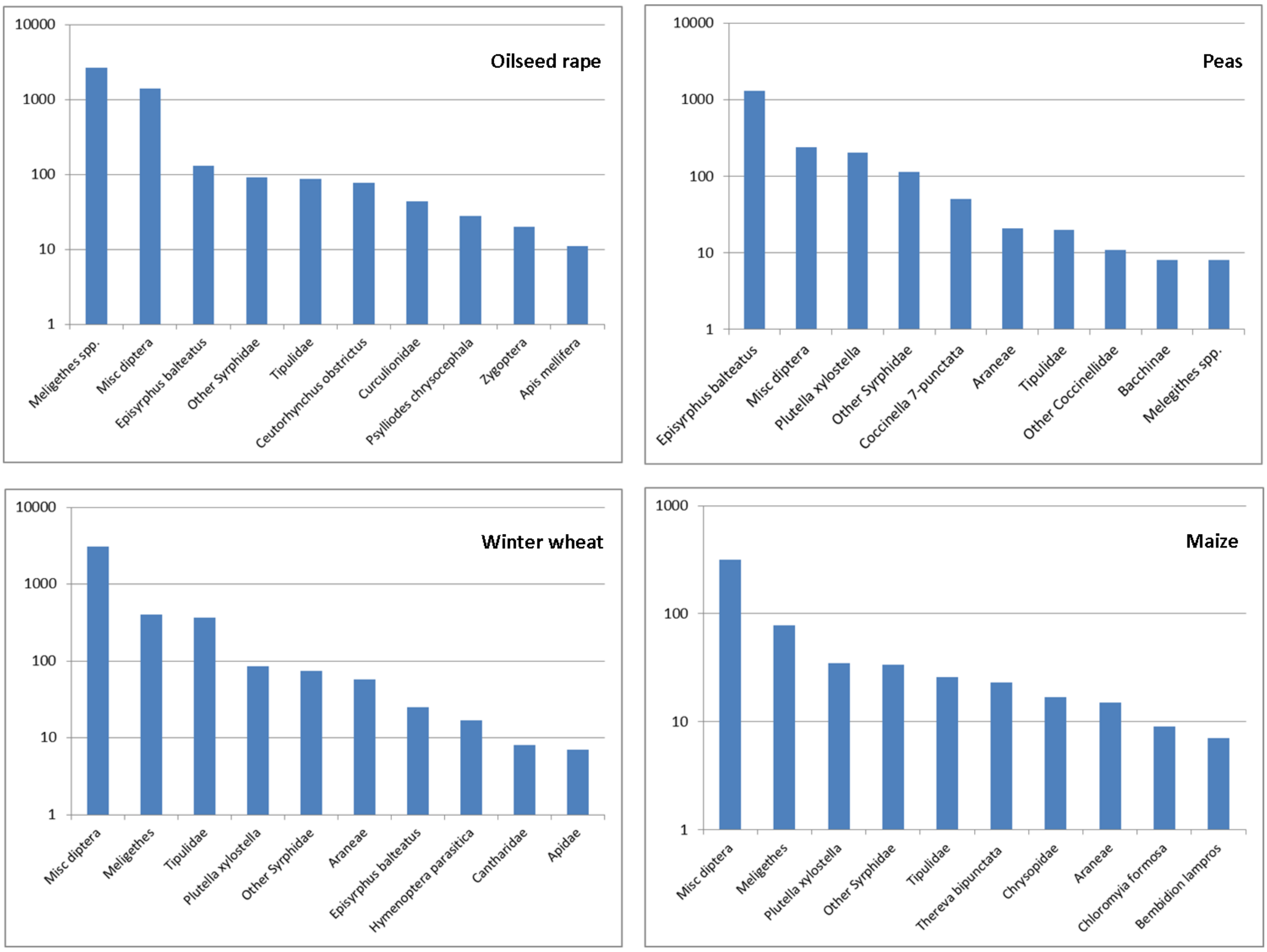


Fig. 2: Frequency diagrams showing the 10 most recorded taxa (as log values) by crop type. Blossom beetle *(Meligethes)* figures for oilseed rape and winter wheat are based on an approximation of numbers present because of the large volumes in which they occurred, but this does not alter the hierarchy shown.

Taxon frequency diagrams **(Figure 2)** demonstrate the top 10 taxa recorded in each crop type over the two survey periods and shows that all crops appear to show at least one dominant group which recorded many more numbers than others present. Miscellaneous diptera and *Meligethes spp.* were the primary taxa recorded in oilseed rape, winter wheat and peas, while in peas *Episyrphus balteatus* was the primary species.

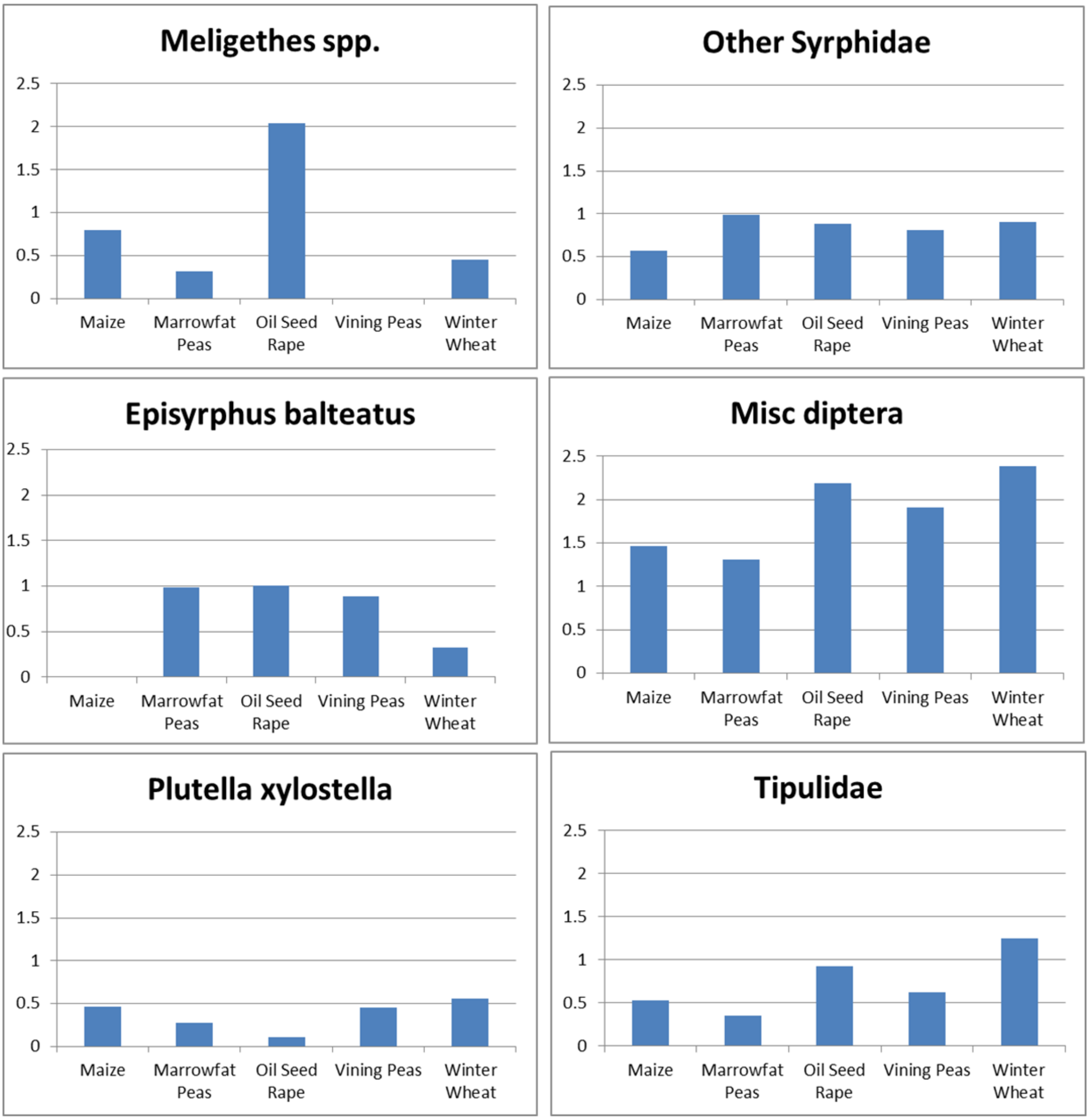


Fig. 3: Summary statistics showing average log abundance by crop for the six most commonly recorded taxa over the two survey visits

Simpson's Index of Diversity (1-D) diversity takes into account both richness and evenness of the data and provides a measure of diversity between 0 and 1 where 1 is the most diverse. Calculations found that maize was the most diverse (1-D = 0.69), closely followed by oilseed rape, then peas and then finally winter wheat (1-D = 0.44).

Analysis of the six most commonly recorded taxa from the study shows the variation in numbers recorded by crop type with maize only bottom of the table in two of the six **(Fig. 3)** and frequently recording higher numbers than marrowfat peas.

Redundancy analysis (RDA) demonstrated that four variables were having the greatest influence on species distribution: crop type, the amount of cultivated land within 500m of the survey site, temperature and insecticide. Partitioning of variance confirmed that these four constrained values alone account for 58.5% of the variation in invertebrate records – a strong result leaving just over 40% of the variation to be explained by all other physical and environmental factors. A permutation test for RDA found that individually crop type and cultivated land were both highly significant ($p < 0.001$) while temperature ($p < 0.008$) and insecticide ($p < 0.01$) were significant to a lesser degree.

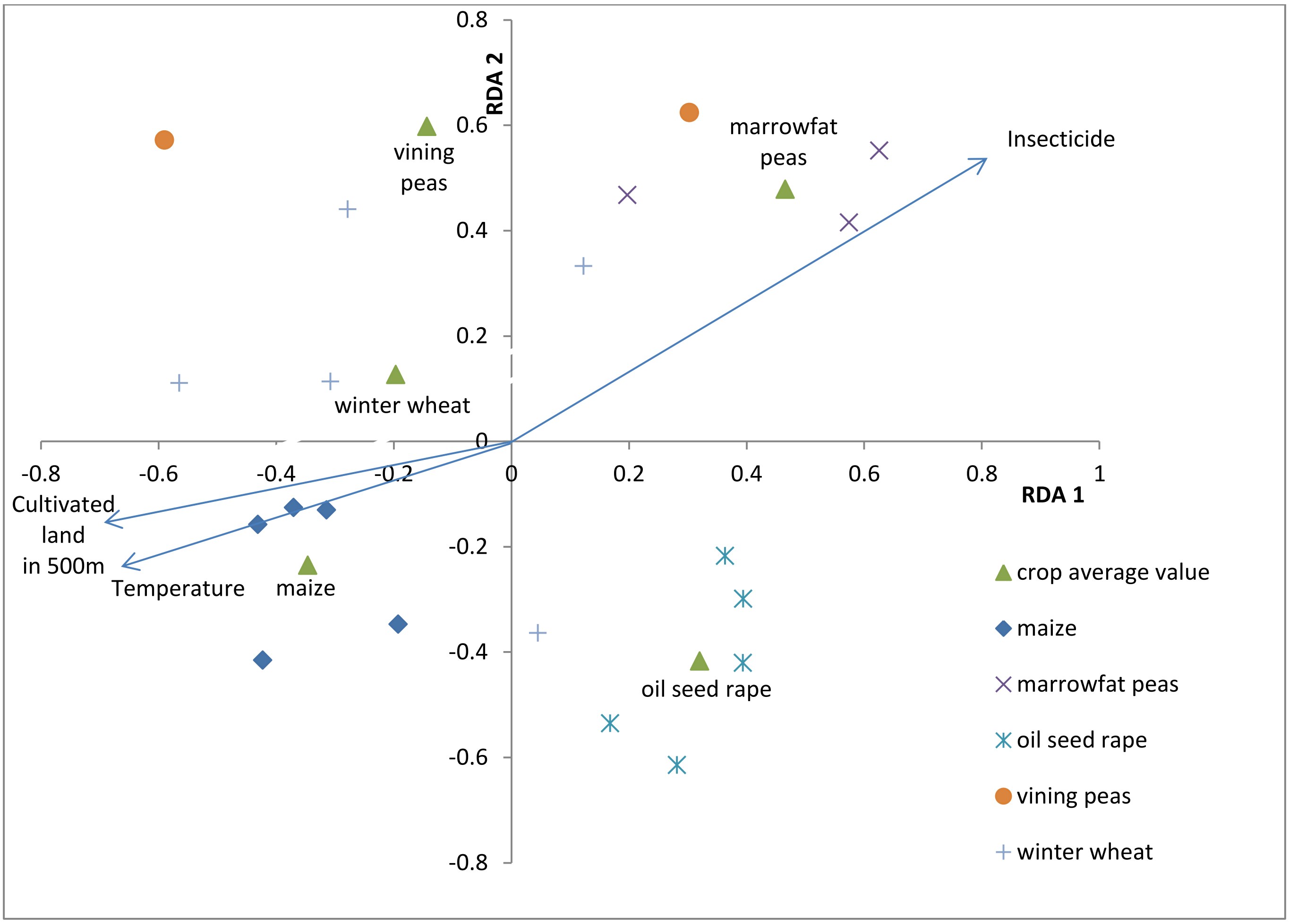


Fig. 4: Redundancy Analysis (RDA) of the different species and groups recorded in each crop type.

RDA analysis demonstrated clusters for some of the crop types surveyed, indicating the presence of distinct insect communities **(Fig. 4)**. Maize sample sites showed a particularly tight clustering, while oilseed rape and marrowfat peas also grouped together. By contrast, winter wheat was much more disparate indicating a much broader community composition. The results also showed an apparent difference between the communities of marrowfat and vining peas and so these were considered separately in subsequent analysis. This analysis also indicated possible correlations between groups of species found in maize and both temperature and the amount of cultivated land within 500m of the sample site.

The RDA analysis for different taxa shows the majority clustering together in the centre indicating little preference for particular variables although some outlying species/groups did appear to correspond to particular crops **(Fig. 5)**. General linear models supported these findings in relation to cabbage seedpod weevil *Ceutorhynchus obstrictus* and blossom beetles *Meligethes spp.* in oilseed rape ($p < 0.00017$ and $p < 0.0024$) and carabid beetles Carabidae in winter wheat ($p < 0.0035$) although the latter were also found to be significantly correlated with vining peas. It is worth noting that *Ceutorhynchus obstrictus*, which only feeds on Brassicaceae, only occurred in oilseed rape. By contrast, general linear models did not support apparent correlations for the three taxa which appeared to cluster most closely to maize – craneflies Tipulidae, green lacewings Chrysopidae and twin spot stiletto fly *Thereva bipunctata* –with Tipulidae instead demonstrating a significant correlation with winter wheat and oilseed rape which may explain its positioning on the RDA analysis. Interestingly however, Chrysopidae were significantly correlated to temperature with higher numbers found during warmer temperatures. What RDA analysis did not illustrate but was identified by general linear models were significant relationships between maize and ground beetles *Pterostichus spp.* as well as carabid beetle *Bembidion lampros* however it should be noted that the latter was only recorded in maize and *Pterostichus spp.* only in maize and one vining pea field.

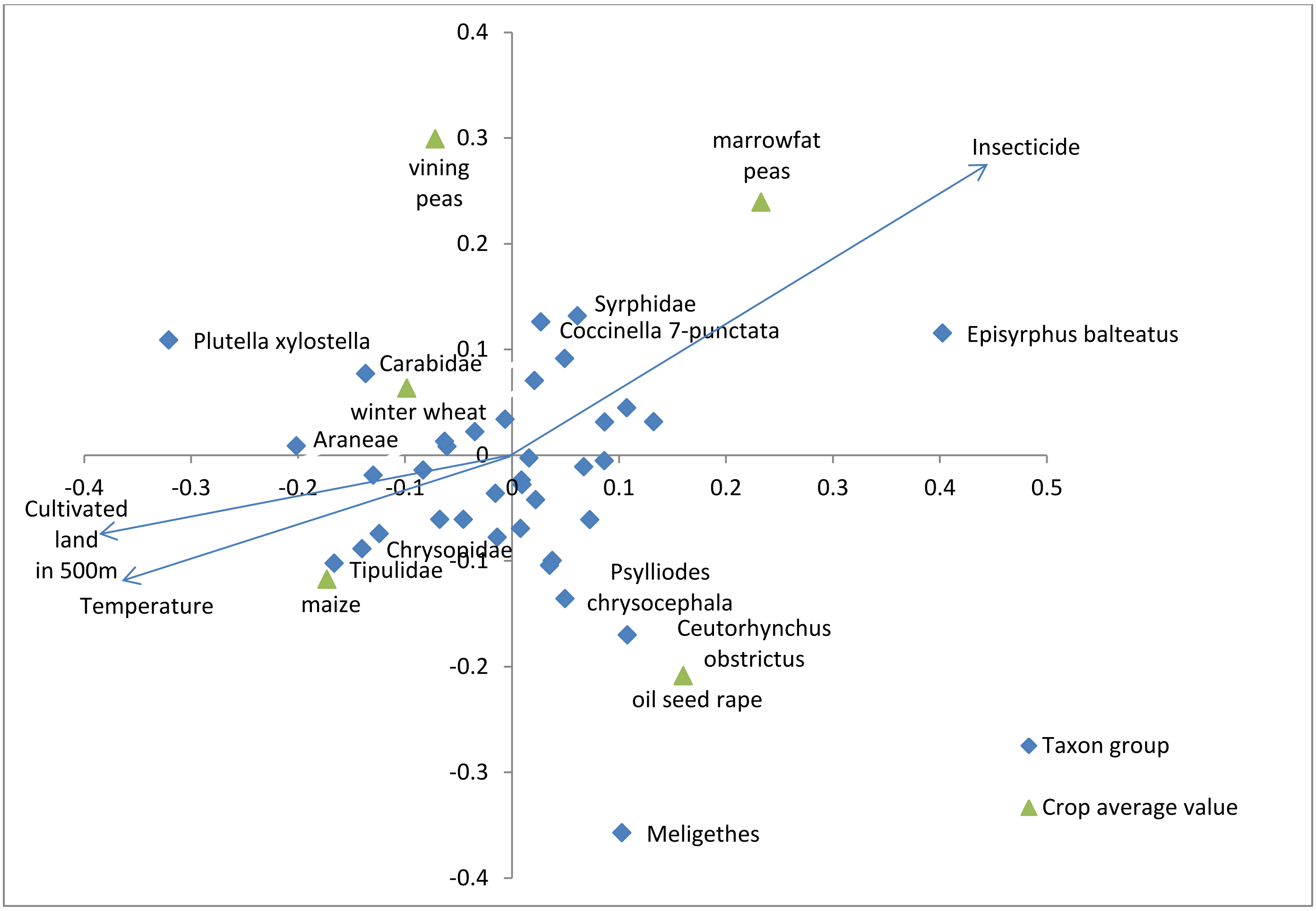


Fig. 5: Redundancy Analysis (RDA) of the individual taxa.

General linear modelling was also used to take into account surrounding land use within a 500m buffer of the survey site. A number of correlations were drawn between different land use variables and particular taxa as shown in **Table 1** helping to identify key habitat features for particular groups. Notable results were positive correlations between amount of grassland and butterflies Lepidoptera (non-*Pieris spp.*), seven-spot ladybird *Coccinella septempunctata* and marmalade hoverfly *Episyrphus balteatus* – the latter being highly significant also being negatively correlated with the amount of cultivated land and open water in the surrounding area.

Overall, 82.2% of the variation in *Episyrphus balteatus* could be explained by these three factors indicating the importance of surrounding land use for that particular species. By contrast, 56% of variation in numbers of cabbage stem flea beetle *Psylliodes chrysocephala* was explained by cultivated land use with a positive correlation indicating an increase in numbers as the amount of arable habitat increased.

Table 1: Significant correlations between taxa and land use within 500m of the survey site

	Land use variable within 500m buffer				
Taxon	**built-up**	**cultivated**	**grassland**	**woodland**	**open water**
Lepidotera, non-*Pieris spp.*			positive**		
Syrphidae (other)		positive*			
Coccinella septempunctata			positive**		
Zygoptera (other)					positive*
Enallagma cyathigerum					positive*
Episyrphus balteatus		negative**	positive***		negative**
Syrphus sp.	negative**				
Chrysomelid larvae					positive*
Psylliodes chrysocephala		positive*			
Tipulidae	negative*			negative*	
Curculionidae		negative**			
Diptera (other)				positive*	

probabilities *<0.05, **<0.01, *<0.001**

A further outcome of the analysis related to insecticide use and its corresponding impact on invertebrate communities. Significant negative correlations were found between applications of insecticide and four taxa: Carabidae (other), *Pterostichus spp., Plutella xylostella* and Curculionidae.

Once field surveys were underway, it became clear that bare ground may be an important factor to consider particularly in the maize fields. Attempts were therefore made to record those species on the bare earth as well as on the plants. Figures indicated that during the first set of surveys the numbers on the ground were more than seven times of that on the crop itself yet during the second set, when crop growth was more advanced, the numbers had reverted to almost seven times more on the plants themselves.

DISCUSSION

In order to understand the potential impact of increased maize cropping our study sought to gain an understanding of pollinator communities found within arable fields by focusing on surveys within the crops themselves. Limited numbers of studies have previously restricted their scope in this way, tending to focus more on comparisons with floral resources and natural habitats in the surrounding landscape. Our research has not only provided a valuable dataset but produced some interesting results in terms of pollinator distribution within farmed landscapes.

What is clear is that while three of our four study crops (maize, winter wheat and peas) do not depend on insect pollination, two-thirds of visitations during our study were associated with these wind and self-pollinated crops. This suggests that these crops still have an important value to invertebrates potentially as a source of pollen, albeit of lower quality (Hanley et al., 2008).

We have shown that crop type is a significant influence on pollinator communities in arable landscapes. It is widely accepted that floral resources exhibit particular traits to appeal to different pollinators (Nicholls and Altieri, 2013) and it was therefore interesting to see the clear clustering of distinct pollinator communities found within maize, oilseed rape and marrowfat peas during this study. Issues around short flowering periods for arable crops providing limited floral resources are well documented (Altieri et al,. 2015) but our results suggest that taxa are not just moving from one resource to another as resources become available but are perhaps being more selective. While modern agroecosystems are known for large areas of uniform floral resources, we have shown that there is still a diverse invertebrate population present and consideration should therefore be given to the extent of large single-crop monocultural blocks versus a landscape where at the field scale, a variety of crops is helping to support a wider range of potential pollinators.

Maize fields were the least well visited in terms of overall numbers of individual invertebrates but our study found that in terms of overall number of taxa, they recorded higher numbers than peas. Species diversity index calculations provide a useful additional interpretation of these results however some caution is necessary in placing too much weight on the figures. Maize was shown to be the most diverse of all four crops surveyed while winter wheat was considered to be the least diverse largely reflecting the dominance of miscellaneous diptera records by some margin in this crop. This is a large order containing many thousands of species, many of which are likely to provide important pollination services (Orford et al., 2015) and if time and budgetary constraints had not limited the opportunity for greater species-level identification it is possible the results would have shown winter wheat to be more diverse. It is likely that the majority of miscellaneous diptera were mostly small calypterates, probably anthomyids whose larvae feed on decaying vegetation, and many flesh flies sarcophagids and blow flies calliphorids suggesting presence of both dung and animal decomposition within the arable environment (Sheppard, 2016). It should also be noted that the dominance of *Episyrphus balteatus* in peas was largely the result of a single marrowfat pea field which accounted for 96% of the total recorded. The larvae of this common species is an aphidophagous predator (Ingels and De Clercq, 2011) and females lay their eggs according to aphid density (Tenhumberg, 1995) which may could explain the large numbers present however it is also likely the elevated levels were the result of a migration event (Sheppard, 2016). Consideration should also be given to the higher numbers of invertebrates recorded in overwintered crops i.e. oilseed rape and winter wheat compared with spring sown maize and peas. Previous research has found that numbers of some invertebrates are higher in autumn sown crops as this provides suitable habitat for species that overwinter as adults or as larvae (Hawes et al., 2009) however it is not possible to determine from the results of this study whether this was having an impact on the communities present.

It should be noted that the survey periods in this study did not enable surveys of maize to be undertaken at its peak growth stages unlike the other crop types studied. It is likely that this would have impacted on the overall numbers of invertebrates present and potentially different taxa too however it is important to demonstrate how visitation rates contrast between crops at different growth points. Oilseed rape crops were dominated by *Meligethes spp.* and miscellaneous diptera, which also impacted on the diversity results. This crop did however support the highest bee Apidae numbers accounting for over half of those recorded throughout the study but with only 11 records for bumblebees *Bombus* despite some previous research concluding that oilseed rape has a positive effect on bumblebees by providing short-term pollen and nectar resources early in the season (Westphal et al, 2003 and Stanley and Stout, 2013). With one exception, records of the domesticated honeybee *Apis mellifera* were confined to just two oilseed rape fields which were geographically close to each other and are likely reflective of proximity to a managed hive in that area. This would confirm findings of previous research which suggests wild pollinators may be providing a greater proportion of pollination services than previously thought (Breeze et al. 2011) but provides a stark reflection of honeybee numbers in a predominately arable landscape. A number of other species were shown to vary significantly with crop type. Some of these were to be expected such as *Ceutorhynchus obstrictus, Psylliodes chrysocephala* and *Meligethes spp.* - major crop pests of oilseed rape (Alford, 2003; Carcamo et al., 2001) while other relationships were indicated between crops and potentially beneficial species in terms of natural pest control such as beetles *Bembidion lampros* and *Pterostichus spp.* in maize and hoverflies Syrphidae and spiders Araneae in peas and winter wheat.

It became apparent early on in the sampling process that due to the later drilling of maize, vegetation levels particularly during the first survey period were much less than for that of other crops giving rise to large areas of bare ground. Exposed soil amongst maize crops has been the cause of much debate in terms of soil erosion concerns (Soil Association, 2015) however bare ground is also known to provide basking habitat for a number of invertebrate species as the soil warms up rapidly in sunshine (Key, 2000) and many species also incubate their eggs in the warm earth. Our study found that during the early growth stages of maize when bare earth was abundant, invertebrate numbers on the ground were significantly higher than on the crop itself although they had reduced by the second survey period when vegetative growth was greater. As this possible relationship was not identified at the start of the study, the data is incomplete and would require further investigation to fully assess the impact of bare ground on the location of invertebrate communities and to compare this with other crop types. It does however present an interesting consideration that, if environmental implications around run-off and diffuse pollution are appropriately managed, there could be habitat benefits for invertebrates. Analysis of the bare ground invertebrate community however shows that just under a quarter of records were for taxa which could be considered agricultural pests and this may therefore have other crop implications.

A large number of studies have considered the importance of habitat diversity within agricultural landscapes to provide forage and nesting habitats for pollinators (Banaszak, 1992; Nicholls and Altieri, 2012) and it was therefore necessary to consider this within our research. We found that surrounding landscape provided significant results for a number of different pollinator species with the amount of cultivated land within 500 metres of the survey site also providing one of the most significant influences on the overall communities present. While increases in the oilseed rape pest cabbage-stem flea beetle *Psylliodes chrysocephala* are perhaps expected to increase with more surrounding arable land providing increased resources for food and egg-laying, the increase in numbers of hoverflies Syrphidae is less clear. It was also interesting to note that the marmalade hoverfly *Episyrphus balteatus* was found to reduce in numbers in line with increasing levels of cultivated land which suggests that relationships based on species information are a more reliable resource, as different traits will result in species-specific responses to land use change (Schweiger et al., 2007). What has been shown through this study however is that all the land-use variables considered - grassland, built-up areas, open water, cultivated land and woodland, were found to significantly influence the numbers of various taxa both positively and negatively. This information, combined with the distinct pollinator communities observed within the majority of the crops surveyed, would provide an additional evidence base on which to demonstrate the importance of heterogeneous habitat resources at a landscape-scale.

Information regarding the application of insecticide was considered of importance to this study because the timescales did not allow for survey planning to factor this in consistently. Instead, by noting the number and dates of applications we were able to look for any significant impacts on pollinator communities and unsurprisingly, insecticide was shown to be one of the four main factors of influence. Insecticide was found to have significant negative effects on just four taxa: Carabidae (other) and more specifically *Pterostichus spp., Plutella xylostella* and Curculionidae. While *Plutella xylostella* and several species of Curculionidae are notable pests particularly of oilseed rape, polyphagous species of Carabidae are generally considered to have benefits as natural pest control agents although to what extent at the field level is the subject of some debate (Kromp, 1999; Lang et al., 1999). It is worth noting that as surveys were undertaken during the day, this may not give a full reflection of the Carabidae populations present as anecdotally some of the larger species such as *Pterostichus* tend to be more nocturnal in nature (Barnes, 2016). Research to consider the impact of pesticides on non-target invertebrates has shown that Carabidae will continue to feed on contaminated prey and ingest lethal levels (Mauchline et al., 2004) and their potential as predators of Curculionidae and *Plutella xylostella* larvae (Suenaga and Hamamura, 1998; Capinera, 2008) could provide a possible explanation for the results found in this study.

It is important to note that this was a pilot study and due to the timescales involved it was not possible to test the methodology in advance to identify all potential issues. Future research would need to consider the sample periods used to try and survey each crop at the same growth stages. Surveys of oilseed rape should ideally have begun earlier than was possible during this study and by the second sample period, the tramlines were in most cases almost completely obscured meaning it was not always possible to complete the two full transects. It should be considered that the method of tramline transects may also have resulted in some insects being driven along by the surveyor resulting in multiple counting (Sheppard, 2016).

CONCLUSION

The study sought to understand the potential impact of increased maize cropping on pollinators and the results have provided an important new body of evidence with which to assess this. By focusing our surveys on what is happening within the individual crops we have been able to collect data on invertebrate communities in a context where previous research is limited.

We have been able to draw five key conclusions:

- Maize supports a varied invertebrate flora, however overall numbers are lower than in other crops.
- Peas were a poorer resource in terms of diversity but higher in individual numbers, with one field contributing a significant proportion of the overall number of records.
- The distinct invertebrate communities demonstrated by maize, oilseed rape and marrowfat peas highlight the importance of having a variety of crops within the landscape.
- Landscape variety is particularly relevant in terms of maize because, for logistical reasons, block cropping in proximity to AD plants results in a more homogenised environment and therefore has the potential to impact on both pollinator numbers and community variation unless carefully managed.
- Consideration should be given to rotations in terms of which crops are being displaced by maize as our research suggests that pollinator communities of oilseed rape may, for example, be less able to adapt to maize than those of winter wheat.

Wider implications of this study

It is acknowledged that a proportion of recorded taxa were those which are considered to be pests of arable crops whose provision of pollination services may be minimal, however there were still a large number of beneficial species present as part of the invertebrate community which could also provide a valuable dataset when considering biological pest control measures.

Pollinator strategies often focus on bee groups and the lack of individuals recorded from this study is notable. While non-bee pollinators are acknowledged as playing a significant role in crop production (Radar et al., 2016) honeybees and wild bees also provide a valuable resource and although it is difficult to put a figure on expected numbers because of issues around abundance monitoring (Vanbergen et al., 2014), this study would suggest that bees generally are in the minority amongst other pollinators in the arable landscape of Greater Lincolnshire. The highest numbers of bees were recorded in oilseed rape while just two individuals were recorded in maize. It is therefore important to consider what maize is replacing in crop rotations in terms of potentially reducing floral resources available to bee pollinators.

Due to a strong body of research on pollinator abundance in field margins, this study did not seek to replicate this however anecdotal evidence from the surveyor indicated that pollinators including bees were more abundant in the margins (Sheppard, 2016) which would accord with research highlighting their importance in providing pollinator forage and nesting habitat on farmland (Stanley and Stout, 2013). This raises an interesting question however around the efficacy of field margins in supporting bee pollinators at a landscape scale as their presence continues to be seemingly confined to the margins themselves and is not translating into a greater abundance within the adjoining crops.

Recommendations for further research

A number of recommendations have been put forward throughout this report for further research to build on the findings of this pilot study. In summary, these include the need to assess maize at a later growth stage which has the potential to provide some very interesting results, particularly as later in the year, harvesting would be well underway for the other crops in our study. It would also be beneficial to repeat the study in a more homogenised landscape to see how pollinator communities respond to a less varied arable environment and finally for further assessment of the importance of bare ground for invertebrates early in the season by looking at a range of arable crops to enable comparisons with the results obtained for maize in this study.

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REFERENCES:

ADAS and Ricardo Energy and Environment (2016) Impacts of bioenergy maize cultivation on agricultural land rental prices and the environment. Defra.

Alford, D. (2003) Biocontrol of Oilseed Rape Pests. Cambridge: Blackwell Publishing

Altieri, M., Nicholls, C., Gillespie, M., Waterhouse, B., Wratten, S., Gbehounou, G. and Gemmill-Herrn, B. (2015) 'Crops, weeds and pollinators: Understanding ecological interaction for better management.' Rome: Food and Agriculture Organisation of the United Nations. [Online] [Accessed on 27 July 2016] http://www.fao.org/3/a-i3821e.pdf

Banaszak, J. (1992) Strategy for conservation of wild bees in an agricultural landscape. *Agriculture, Ecosystems and Environment* 40(1-4), pp179-192

Barnes, C. (2016) Comments on paper to Sarah Baker. 10th November

Biesmeijer, J., Roberts, S., Reemer, M., Ohlemuller, R., Edwards, M., Peeters, T., Schaffers, A., Potts, S., Kleukers, R., Thomas, C., Settele, J. and Kunin, W. (2006) 'Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands' *Science* 313(5785) pp. 351-354
Defra (2014) Defra June Survey 1905 - 2013

Bohan, D. and Heard. M (2008) 'Weed and invertebrate community compositions in arable farmland'. *Arthropod-Plant Interactions* 2( ) pp. 21-30.

Breeze, T., Bailey, A., Balcombe, K. and Potts, S. (2011) 'Pollination services in the UK: How important are honeybees?' *Agriculture, Ecosystems and Environment*. 123(2011) pp.123-143

Capinera, J. (2008) Encyclopedia of Entomology. USA: Springer

Carreck, N. and Williams, I. (1998) 'The economic value of bees in the UK.' *Bee World*, 79(1998) pp. 115-123.

Defra (2014) Farming Statistics. Final crop areas, yields, livestock populations and agricultural workforce at June 2014 - United Kingdom.

Defra (2014) Defra June Survey 1905 - 2013

Farnworth, G. and Melchett, P. (2015) *Runaway Maize: Subsidised soil destruction.* Bristol: Soil Association https://www.soilassociation.org/media/4671/runaway-maize-june-2015.pdf

Garibaldi, L. et al (2013) Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance. *Science* 339(6127) pp. 1608-1611

Garratt M.P.D. (2013) Sustainable pollination services for UK crops. Antenna. 37 (1): pp 39-41

Hawes, C., Haughton, A., Bohan, D. and Squire, G. (2009) 'Functional approaches for assessing plant and invertebrates abundance patterns in arable systems.' *Basic and Applied Ecology* 10(1) pp. 34-42

Ingels, B. and De Clercq, P. (2011) 'Effect of size, extraguild prey and habitat complexity on intraguild interactions: a case study with the invasive ladybird Harmonia axyridis and the hoverfly Episyrphus balteatus.' *BioControl* 56(6) pp. 871–882

Jauker, F., Bondarenko, B., Becker, H. C. and Steffan-Dewenter, I. (2012) Pollination efficiency of wild bees and hoverflies provided to oilseed rape. *Agricultural and Forest Entomology*, 14(1) pp. 81–87

Kennedy, K. et al (2013) 'A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems.' *Ecology Letters* 16(2013) pp. 584-599

Key, R. (2000). Bare ground and the conservation of invertebrates. British Wildlife 11(2000) 183–191.

Klein, AM., Vaissière, b., Cane, J., Steffan-Dewenter, I., Cunningham, S., Kremen, C. and Tscharntke, T. (2007) 'Importance of pollinators in changing landscapes for world crops.' *Proceedings of the Royal Society B* 274(1608) pp. 303-313

Kromp, B. (1999) Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement. *Agriculture, Ecosystems and Environment* 74(1-3) pp. 187-228.

Lang, A., Filser, J. and Henschel, J. (1999) 'Predation by ground beetles and wolf spiders on herbivorous insects in a maize crop.' *Agriculture, Ecosystems and Environment* 72(2) pp. 189-199

Larson, B. Kevana, P. and Inouyea, D. (2011) 'Flies and flowers: taxonomic diversity of anthophiles and pollinators.' *The Canadian Entomologist* 133(4) pp. 439-465

Mauchline, A., Osborne, J. and Powell, W. (2004) 'Feeding responses of carabid beetles to dimethoate-contaminated prey.' *Agricultural and Forest Entomology* 6(2) pp. 99-104

Nicholls, C. and Altieri, M. (2013) 'Plant biodiversity enhances bees and other insect pollinators in agroecosystems. A review.' Agronomy for Sustainable Development 33(2) pp. 257–274

Nicholson, J. (2016) *Growing maize.* Presentation to The Growth of Maize event. 2nd November

Öckinger, E. and Smith, H. (2007) 'Semi-natural grasslands as population sources for pollinating insects in agricultural landscapes.' *Journal of Applied Ecology*, 44 (2007) pp. 50–59

Orford, K., Vaughan, I. and Memmott, J. (2015) 'The forgotten flies: The importance of non-syrphid Diptera as pollinators.' *Proceedings of the Royal Society B: Biological Sciences* 282(2015)

Pollard E. and Yates, T. (1993) *Monitoring Butterflies for Ecology and Conservation*. Chapman and Hall, London.

Potts, S., Roberts, S., Dean, R., Marris, G., Brown, M., Jones, R., Neumann, P. and Settele, J. (2010) 'Declines of managed honey bees and beekeepers in Europe.' *Journal of Apicultural Research* 49(1) pp. 15-22.

Rader. R et al. (2016) 'Non-bee insects are important contributors to global crop pollination.' *Proceedings of the National Academy of the Sciences of the United States of America* 113(1) pp. 146-151

Raymond, L., Sarthou, J.P., Plantegenest, M. Gauffre, B., Ladet, S. and Vialatte, A. (2014) 'Immature hoverflies overwinter in cultivated fields and may significantly control aphid populations in autumn.' *Agriculture, Ecosystems and Environment* 185(2014) pp. 99-105.

Richards, A. (2001) 'Does Low Biodiversity Resulting from Modern Agricultural Practice Affect Crop Pollination and Yield?' *Annals of Botany* 88(2001) pp. 165-172

Schlinkert H, Westphal C, Clough Y, László Z, Ludwig M, Tscharntke T (2015) Plant Size as Determinant of Species Richness of Herbivores, Natural Enemies and Pollinators across 21 Brassicaceae Species. PLoS ONE 10(8)

Schweiger O., Musche M., Bailey D., Billeter R., Diekötter T., Hendrickx F., Herzog F., Liira J., Maelfait JP., Speelmans M. and Dziock F. (2007) Functional richness of local hover-fly communities (Diptera, Syrphidae) in response to land use across temperate Europe. *Oikos* 116(3) pp. 461–472

Sheppard, D. (2016) *Pollinator project*. Email to Sarah Baker. 17th August

Stanley, D.A. and Stout, J.C. (2013) 'Quantifying the impacts of bioenergy crops on pollinating insect abundance and diversity, a field scale valuation reveals taxon-specific responses.' *Journal of Applied Ecology*, 50, pp. 335–344

Tenhumberg, B. (1995) 'Estimating Predatory Efficiency of Episyrphus balteatus (Diptera: Syrphidae) in Cereal Fields.' *Environmental Entomology* 24(3) pp. 687-691

Vanbergen, A., Heard, M., Breeze, T., Potts, S. and Hanley, N. (2014) *Status and value of pollinators and pollination services*. [Online] [Accessed on 27th July 2016] https://consult.defra.gov.uk/plant-and-bee-health-policy/a-consultation-on-the-national-pollinator-strategy/supporting_documents/140314%20STATUS%20AND%20VALUE%20OF%20POLLINATORS%20AND%20POLLINATION%20SERVICES_FINALver2.pdf

Vogel, B. and Hellawell, R. (2011) On Farm Anaerobic Digestion as an Integral Part of Profitable and Sustainable Farming in the UK. Unknown place of publication: Masstock and Renewable Energy Association. [Online] [Accessed on 27 July 2016] http://www.biogas.org.uk/pdf/rea-biogas-masstock-crop-feedstocks-in-on-farm-ad-1.pdf

Walther-Hellwig, K. and Frankl, R. (2000) 'Foraging habitats and foraging distances of bumblebees, Bombus spp. (Hym., Apidae), in an agricultural landscape.' *Journal of Applied Entomology* 124(7-8) pp. 299-306

Westphal, C., Steffan-Dewenter, I. and Tscharntke, T. (2003) 'Mass flowering crops enhance pollinator densities at a landscape scale.' *Ecology Letters*, 6, August, pp. 961-965

Woodcock, B., Edward. M., Redhead, J., Meek, W., Nuttall, P., Falk, S., Nowakowski, M. and Pywell, R. (2013) 'Crop flower visitation by honeybees, bumblebees and solitary bees: Behavioural differences and diversity responses to landscape. *Agriculture, Ecosystems and Environment* 171(2013) pp. 1-8

Assessing the impact of increased maize cropping on pollinators

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