A restatement of recent advances in the natural science evidence base concerning neonicotinoid insecticides and insect pollinators

H. Charles J. Godfray, Tjeerd Blacquière, Linda M. Field[3], Rosemary S. Hails, Simon G. Potts, Nigel E. Raine, Adam J. Vanbergen & Angela R. McLean

Oxford Martin School Restatement Project No. 3.

Restatements are reviews of the natural science evidence base underlying areas of current policy concern and controversy. They are written in terms that are as policy neutral as possible and are designed to be read by an audience that is well-informed but does not have specialist technical knowledge. The evidence base is summarised in a series of paragraphs each of which includes an assessment of the nature of the evidence. Restatements are produced by a writing team reflecting the breadth of opinion on the topic in the science community and involve wide consultation with interested stakeholders. The final version is submitted for peer review in a scientific journal.

This pdf contains:

Pages 2-3   A short paper describing the restatement project

Pages 4-7   The restatement itself which is the formal appendix of the paper

Pages 8-15   An annotated bibliography of the evidence underlying the restatement (formally the Electronic Supplementary Material accompanying the paper)

The paper is open access and can be freely distributed in its original version.

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A summary is provided of recent advances in the natural science evidence base concerning the effects of neonicotinoid insecticides on insect pollinators in a format (a 'restatement') intended to be accessible to informed but not expert policymakers and stakeholders. Important new studies have been published since our recent review of this field (Godfray *et al.* 2014 *Proc. R. Soc. B* **281**, 20140558. (doi:10.1098/rspb.2014.0558)) and the subject continues to be an area of very active research and high policy relevance.

1. Introduction

Neonicotinoid insecticides were introduced in the 1990s and their market share quickly expanded to approximately a third of the global insecticide total by value. They are used in different ways, but particularly as seed treatments where the chemical is absorbed by the growing plant and is distributed through all tissues at concentrations that can kill insect herbivores. However, neonicotinoids are also translocated to nectar and pollen where they can be consumed by pollinating insects. Numbers of pollinators have declined in agricultural landscapes and there is concern that the introduction and widespread use of neonicotinoids is partly responsible.

In December 2013, the European Union (EU) instigated partial restrictions on the use of neonicotinoid insecticides on crops that might be used as food by pollinating insects. This move is strongly opposed by many in the farming community and there has been a vigorous debate focusing on the scientific evidence that neonicotinoids harm pollinators, as well as the environmental and economic costs and benefits of the restrictions.

To try to assist the debate we produced a 'restatement' of the underlying natural science evidence base in a form that was intended to be accessible to informed but not expert policymakers and stakeholders [1]. Our avowed aim was to be as policy-neutral as possible while acknowledging that perfect neutrality is never achievable. The restatement was published as an appendix to a short paper in this journal accompanied by an extensive annotated bibliography as the electronic supplementary material.

Since the restatement was published the debate about restricting neonicotinoid use has continued unabated. Farming organizations have successfully

applied for '120-day derogations' from the restrictions in several European countries (see electronic supplementary material, paragraph A.2) on the grounds of lack of alternative pest-management options, moves that have been criticized by environmental non-governmental organizations. The EU is committed to review the restrictions in 2015–2016 and through the independent European Food Safety Authority opened a call for evidence (closing 30 September 2015; http://www.efsa.europa.eu/en/data/call/150522). Much new research has been published on the topic (we review over 80 studies here) including the largest replicated field study to date [2].

Despite the relatively short time since the restatement was published we provide here an update in the same format. We do this (i) because of the significant advances in the science; (ii) because of the continuing need for policy-neutral evidence summaries in this highly contested area, especially in the run up to the review of the EU restrictions; and (iii) in response to a request to do so by the UK Government Chief Scientific Adviser.

2. Methods

The literature on pollinators and neonicotinoids published since our restatement was completed was reviewed and a first draft evidence summary produced by a subset of the authors. All authors reviewed and revised the document, and agreed on the categorizing of the different evidence components using the same scheme we adopted earlier, and which is explained in paragraph A2 of the restatement update (appendix A). The second draft was sent to a series of stakeholders or stakeholder groups including scientists involved in pollinator research, representatives of the farming and agrochemical industries, non-governmental organizations concerned with the environment and conservation, and UK government departments and statutory bodies responsible for pollinator policy. The document was revised in the light of much helpful feedback from over 40 stakeholders (see acknowledgements). Though many groups were consulted, the project was conducted completely independent of any stakeholder and was funded by the Oxford Martin School (part of the University of Oxford).

3. Results

The update to the restatement of the natural science evidence base concerning neonicotinoid insecticides and insect pollinators is given in appendix A, with an annotated bibliography provided as the electronic supplementary material.

4. Discussion

The new evidence and evidence syntheses that have been published in the last 18 months (between February 2014 and August 2015) significantly advance our understanding of the effects of neonicotinoids on insect pollinators. Nevertheless, major gaps in our understanding remain, and different policy conclusions can be drawn depending on the weight one accords to important (but not definitive) science findings and the weightings given to the economic and other interests of different stakeholders. The natural science evidence base places constraints on policies that claim to be consistent with the science, but does not specify a single course of action.

We also raise an issue here that arises from our original study but is not directly relevant to the evidence base on the effects of neonicotinoids on pollinators. In introducing the subject we wrote 'Neonicotinoid insecticides are a highly effective tool to reduce crop yield losses due to insect pests', and in the restatement itself listed a small number of papers in the scientific literature to support this statement [1]. It has been pointed out that some of these papers were funded by industry and that there are other studies that have recorded no benefits of neonicotinoid use (e.g. [3]).

The efficacy of neonicotinoids is clearly an important issue, and we believe few would doubt that in some circumstances (combinations of crops, pests and locales) they are highly effective and in other circumstances they do not justify the costs of their purchase. We did not attempt to review this subject and should have been more careful to say we were not commenting on efficacy *per se*.

Though a meta-analysis of efficacy would be very informative it would also be very difficult. Efficacy studies are largely conducted by industry, the sector that benefits most from the data, and are not the type of science usually funded by public organizations. Typically, the studies are not published in the peer-reviewed literature (though they are often made available to regulators) and some are kept confidential for commercial reasons. Efficacy trials are expensive and it seems unlikely that they will ever be publicly funded at scale. It is an interesting topic for debate whether industry would benefit in the long run from placing more of its data in the public domain as well as putting in place measures to increase public confidence in studies they fund themselves. The recent movement in the pharmaceutical sector to set up trial registries (see https://clinicaltrials.gov/ct2/home and https://www.clinicaltrialsregister.eu) provides a model for how the latter might be achieved.

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Appendix A. 'A restatement of recent advances in the natural science evidence base concerning neonicotinoid insecticides and insect pollinators'

For an annotated bibliography of the evidence supporting each statement (hereafter 'Annotated Bibliography') see the electronic supplementary material.

(a) Introduction and aims

A1 This document is an update to our previous 'restatement' of the natural science evidence base concerning neonicotinoid insecticides and insect pollinators. It does not repeat evidence presented earlier and concentrates on material published between February 2014 and August 2015. It is arranged in the same six sections (a–g). Paragraphs are numbered A1, A2, etc. and the symbol § (e.g. §16) is used to indicate the paragraph number in the original document [1], where the same subject was treated.

A2 (§1) The restrictions on the use of certain neonicotinoids as seed coatings on crops attractive to pollinating bees will have been in place for two years in December 2015. The Commission has now mandated the European Food Safety Authority to collate relevant data as the first step in the review of these measures. Industry groups in a number of EU countries have successfully applied for '120-day' derogations to use restricted neonicotinoids in defined geographical areas on the grounds of the absence of viable alternatives (see also A33). The province of Ontario in Canada is introducing restrictions on neonicotinoid use on maize (corn) and soy from July 2015. We are not aware of other equivalent measures that have been introduced elsewhere in the world.

A3 (§2) As before the authors provide a consensus judgement on the nature of the different evidence components. We use the following descriptions, which explicitly are not a ranking, indicated by abbreviated codes. Statements are considered to be supported by:

[D_{ata}] A strong evidence base involving experimental studies or field *data* collection, with appropriate detailed statistical or other quantitative analysis.

[E_{xp_op}] A consensus of *expert opinion* extrapolating results from related ecological systems and well-established ecological principles.

[S_{upp_ev}] Some *supporting evidence* but further work would improve the evidence base substantially.

[P_{rojns}] *Projections* based on the available evidence for which substantial uncertainty often exists that could affect outcomes.

(b) Pollinators and neonicotinoid insecticides

A4 (§§4–11) In the Annotated Bibliography we list new references relevant to the introductory material in this section.

(c) Exposure of pollinators to neonicotinoid insecticides

A5 (§§13–14) As in the first version of the restatement we consider concentrations of neonicotinoids in pollen and nectar of the order of $2-6 \, \text{ng g}^{-1}$ to be typical of those that a pollinator might encounter when foraging on seed-treated crops. Statements about low or high concentrations are made relative to this benchmark, though we acknowledge there will be variation around these figures and that this benchmark involves an element of expert judgment. A wide-ranging review of how neonicotinoids, introduced as seed coatings, may move through and persist in the environment has been published. [E_{xp_op}]

A6 (§15) There is evidence that contaminated dust expelled into the environment from drilling machines during the planting of seeds treated with neonicotinoids can continue to pose threats to honeybees. [D_{ata}]

A7 (§16) There continues to be intensive study of movement of neonicotinoids through the environment and their effect on non-pollinating organisms. This topic is outside the scope of this restatement though in the Annotated Bibliography we provide an entry into this literature. [E_{xp_op}]

A8 (§18) A laboratory study of honeybee and bumblebee (*Bombus terrestris*) behaviour showed that foraging-age insects do not avoid food sources containing imidacloprid, thiamethoxam or clothianidin at field relevant concentrations (approx. $0.25-3 \, \text{ng g}^{-1}$). The bees do not seem able to 'taste' these compounds though there is evidence that the first two stimulate feeding. The response is affected by insect age: newly emerged honeybees and bumblebees largely avoid imidacloprid-contaminated sugar solution. [D_{ata}] These results suggest that it may be less likely that individual flower-visiting bees will reduce their pesticide exposure by avoiding flowers in the field contaminated by insecticides, but this needs to be tested in the field. [E_{xp_op}]

A9 (§20) Honeybee colonies placed in or beside fields of flowering oilseed rape (canola) forage extensively on the crop, though those situated further away may use it much less, even in landscapes where it is the dominant bee-attractive crop. There is limited evidence for similar patterns in other bee species. [D_{ata}]

A10 (§21) *Summary.* Some information is available on the extent to which pollinators are exposed to neonicotinoids through different pathways in the environment. Most exposure will be at sublethal levels from foraging on seed-treated plants, the most important exception being contamination from dust at the time of planting, especially when regulations and best practice are not followed. Better quantitative data on typical concentrations in nectar and pollen of non-crop plants in agricultural landscapes and the extent of exposure through planting dust and other sources is desirable, as is improved data on how different species of pollinating bees collect food in different landscapes. [E_{xp_op}]

(d) Laboratory studies of lethal and sublethal effects of neonicotinoids

A11 (§§22–27) New reviews of the literature on lethal and sublethal effects of neonicotinoids on pollinators, and a large literature survey, have been published. [E_{xp_op}]

A12 (§25) Further studies have shown the potential of neonicotinoids to cause detrimental sublethal effects in different species of flower-visiting bees, as well as the complexity of the physiological response of larval and

adult honeybees to acute and chronic sublethal neonicotinoid exposure. How sublethal doses of neonicotinoids affect behavioural processes such as homing ability in honeybees is strongly context-dependent (affected by, for example, temperature and landscape structure) complicating the design of standard assays of sublethal effects. Recent studies have associated chronic low doses of neonicotinoids with neuronal dysfunction in the brain of bumblebees and increased vulnerability to other neural stressors. [D_{ata}]

A13 (§26) There is some new evidence that biological and non-biological stresses can exacerbate sublethal effects of neonicotinoids, though such effects are not universal and are difficult to predict. [S_{upp_ev}]

A14 (§27a) A new survey of toxicity data shows that the relative sensitivity to different pesticides of honeybees and other pollinating bees is highly variable [D_{ata}], which limits the degree to which honeybee data can be extrapolated to other sentinel species. [E_{xp_op}]

A15 (§28) *Summary.* Data continue to accumulate showing that sublethal neonicotinoid exposure can affect many aspects of pollinator behaviour and physiology (though most studies involve honeybees or bumblebees). Sublethal effects at field-realistic doses are now established, but their consequences for pollinator populations and pollination are still unclear. Responses to neonicotinoids vary across bee species and are affected by type of exposure (for example, acute versus chronic or oral versus contact), which makes generalisations difficult. [E_{xp_op}]

(e) Neonicotinoid residues observed in pollen, nectar and wax in the field

A16 (§§29–31) New data, data compilations and reanalyses of earlier data continue to show that neonicotinoid residues can be detected in pollen and nectar collected by pollinating bees. However, these data are highly variable, making general inference hard. [S_{upp_ev}] Incidences of high neonicotinoid residues that would almost certainly cause acute toxic effects in honeybees and bumblebees do occur, but not commonly. [E_{xp_op}]

A17 (§32) *Summary* (*unchanged from earlier restatement*). Neonicotinoids can be detected in wild pollinators as well as honeybee and bumblebee colonies but data are relatively few and restricted to a limited number of species. Studies to date have found low levels of residues in surveys of honeybees and honeybee products. Observed residues in pollinating bees and the products they collect will depend critically on details of spatial and temporal sampling relative to crop treatment and flowering. [E_{xp_op}]

(f) Experiments conducted in the field

A18 (§33) As before, we give separate, detailed treatment to 'semi-field' studies where insects are exposed by the experimenter to a known dose of insecticide and then allowed to forage in the environment, and 'true field' studies involving exposure to neonicotinoids as applied in actual farm landscapes. There is continuing debate about the relevance of the doses and application

methods used in semi-field studies, and about the relevance of methodologies used in true field experiments. [E_{xp_op}]

A19 *Dively et al.* [4] provided replicate colonies of honeybees over a 12-week period with supplemental pollen paste diets containing imidacloprid at three concentrations (5, 20 and 100 ng g^{-1}) with a fourth control treatment. Experiments were conducted in 2009 (10 replicates per treatment) and 2010 (seven replicates). They found no effect on foraging performance or colony health in the short term but over a longer period, colonies exposed to neonicotinoids were more likely to lose queens, suffer higher overwintering mortality and have greater *Varroa* infestations, though these effects were only statistically significant at the high (20) and very high (100 ng g^{-1}) concentrations. [D_{ata}] The authors concluded that their results did not suggest that neonicotinoids were a sole cause of colony collapse. [P_{rojns}]

A20 *Lu et al.* [5]. Honeybee colonies were fed with syrup containing high concentrations of imidacloprid or clothianidin, or with no added insecticide, for a 13-week period from July to September (in Massachusetts, USA). A detrimental effect of neonicotinoids on successful overwintering was reported though we have concerns (see Annotated Bibliography) about how this conclusion was reached. [E_{xp_op}]

A21 (§37) *Gill & Raine* [6] reported how the day-to-day foraging patterns of 259 bumblebee (*B. terrestris*) workers from 40 colonies were affected by individual or combined exposure to the neonicotinoid imidacloprid and the pyrethroid λ-cyhalothrin. These data, and results presented by *Gill et al.* [7], were collected in the same experiment conducted in 2011 (see §37). Exposure to imidacloprid concentrations (10 ng g^{-1}) towards the high end of what is typically observed in the field led to acute and chronic effects on individual foraging behaviour (although actual imidacloprid consumption by individual workers will have been diluted by foraging from untreated floral sources in the field; see §37). Whereas individual bumblebee foraging efficiency normally improves with experience, this did not occur in individuals exposed to imidacloprid. [D_{ata}] Evidence was found that the insecticide affected the pollinators' preference for different flowers as sources of pollen. [S_{upp_ev}]

A22 *Moffat et al.* [8]. Bumblebee (*B. terrestris*) colonies were provided with syrup containing low doses (approx. 2 ng g^{-1}) of imidacloprid and placed in the field in a non-intensive agricultural location for 43–48 days. By most measures, the neonicotinoid had a significantly negative effect on colony performance compared with controls. [D_{ata}]

A23 (§38) A true field experiment by Thompson *et al.* [9] was originally interpreted as showing no effects of two neonicotinoids on bumblebee (*B. terrestris*) colony performance. The experiment placed multiple colonies adjacent to oilseed rape fields that had received different insecticide treatments (but with no replication at the field level). A colony-level reanalysis of the data by Goulson [10] showed a significant relationship between neonicotinoid concentration and performance: colonies with higher concentrations of thiamethoxam or clothianidin in nectar, or thiamethoxam in pollen stores, produced significantly fewer new queens. Because

exposure was not manipulated at the colony level, this study should be considered as correlational rather than experimental. [P$_{rojns}$]

A24 *Cutler et al.* [11]. Ten 2-hectare plots in Southern Ontario, Canada, were planted with oilseed rape, half of which were planted with seed treated with the neonicotinoid clothianidin with the other half controls. During peak flowering, four honeybee hives were placed in the centre of each field for two weeks before being moved to a site away from insecticide treated crops. Pollen from hives in treated fields had higher concentrations of clothianidin (which were non-zero in controls) but no effects of the insecticide were found for a variety of honeybee colony growth or overwintering metrics. [D$_{ata}$]

A25 *Cutler & Scott-Dupree* [12]. Bumblebee (*Bombus impatiens*) colonies were placed beside four fields planted with organic maize and four with maize grown from neonicotinoid-coated seeds in Southern Ontario, Canada. The study took place on commercial farms and organic and non-organic maize produced pollen at different times. No differences were found in ten measures of colony health, except that colonies by treated fields had significantly fewer workers (which the authors attributed to an effect of crop development time). Analysis of collected pollen showed maize was a very small component (0–2%) of these bumblebees' diets. [D$_{ata}$]

A26 *Rundlöf et al.* [2]. In southern Sweden eight pairs of spring-sown oilseed rape fields were chosen with one of each pair grown from clothianidin coated seeds and the other from non-coated seeds. The seed treatment used, as recommended by the manufacturer, led to higher concentrations of clothianidin in pollen than is normally observed in this crop. Treated fields had lower densities of solitary bees and bumblebees, and poorer bumblebee (*B. terrestris*) colony growth and queen production (all comparisons statistically significant). Solitary bees (*Osmia bicornis*) placed adjacent to treated fields all disappeared while a small but significantly higher number nested beside control fields. The experiment detected no significant effects on measures of honeybee colony strength. Wildflowers, to which pollinators may also be exposed, had higher levels of clothianidin when growing in uncultivated land around treated compared to untreated crops. [D$_{ata}$]

A27 (§40) *Summary.* Evidence continues to accumulate from semi-field experiments that sublethal exposure to neonicotinoid insecticides, chiefly but not exclusively at the high end of what is likely to be experienced in the environment, can affect foraging and other behaviours in the field. Several true field studies have reported no effect of exposure to neonicotinoid-treated crops on honeybee colony performance, but the first large-scale study of the exposure of bumblebees (see A26) found strong evidence of harmful effects. There is very little information about the effects of neonicotinoids on non-bee pollinators. [E$_{xp\_op}$]

(g) Consequences of neonicotinoid use

A28 (§41) A new, open access computer model of honeybee colony performance has been developed that could help integrate the effects of different stressors (including insecticide exposure on colony performance). Models

of the effects of sublethal stress, including insecticide exposure, on bumblebee colony dynamics and failure rates have also been developed. [E$_{xp\_op}$]

A29 *Budge et al.* [13] collected data on honeybee colony in-season loss and neonicotinoid use from nine regions of the UK every other year from 2000 to 2010. Controlling for region (but not year) they find a weak but significant correlation between colony loss and imidacloprid use, but not total neonicotinoid use. We found that this effect was due to a correlation between annual average colony loss and imidacloprid use. Imidacloprid use peaked mid-decade (after which it was replaced by thiamexotham and clothianidin) and there was a tendency for honeybee losses to be higher at this time. Because other factors not included in the analysis may show similar annual patterns, and because of statistical issues with the analysis (see Annotated Bibliography), the correlation of honeybee colony losses with imidacloprid use, and the lack of correlation with total neonicotinoid use, should be treated with great caution. [E$_{xp\_op}$]

A30 (§42) A meta-analysis suggests that 80% of the pollination of global crops for which wild bees are responsible can be attributed to the activities of just 2% of species. These also tend to be species that are most responsive to interventions designed to increase bee densities. [E$_{xp\_op}$] The most important species of wild bees in Europe and North America are common species of bumblebee (*Bombus* spp.) underlying the importance of understanding their interaction with insecticides. [E$_{xp\_op}$]

A31 (§43) Evidence continues to accumulate on the drivers of pollinator decline. Analyses of the extinction rates (since 1850) and changes (1921–1950 versus 1983–2012) in species richness and composition of bees and wasps in the UK suggests land use and management changes are the most important historical drivers with major faunal losses occurring early in the twentieth century. Any effects of changes in pesticide use over recent decades are unlikely to be picked up by these analyses. An analysis of the historical shifts in the ranges of European and North American bumblebees showed that they have failed to track climate warming at their northern range limits, while southern range limits have contracted. These shifts were independent of changes in land use (both continents) and pesticides application, including neonicotinoids (in North America only; pesticide data was unavailable for Europe). This study only assessed changes in species range distributions, and so any impacts of pesticides on population density or diversity at finer habitat or landscape scales would not be identified. [S$_{upp\_ev}$]

A32 (§44) Updates on overwintering honeybee colony loss in Europe and North America (USA and Canada) have been published. [D$_{ata}$]

A33 (§45) There are still few data examining the effects of the neonicotinoid restrictions on pest numbers and consequently on crop yields and income, on farmers' decisions about whether to grow crops subject to restriction, or on alternative pest-management strategies used by farmers. A recently published study suggests farmers that use neonicotinoid seed treatments on oilseed rape in the UK use fewer subsequent foliar insecticide applications in the autumn but with no overall effect on applications at flowering time. [E$_{xp\_op}$]

A34 (§46) *Summary*. There still remain major gaps in our understanding of how pollinator colony-level (for social bees) and population processes may dampen or amplify the lethal or sublethal effects of neonicotinoid exposure and their effects on pollination services; as well as how farmers might change their agronomic practices in response to restrictions on neonicotinoid use and the resulting positive or negative effects on pollinators and pollination. While these areas continue to be researched there is still a limited evidence base to guide policymakers on how pollinator populations will be affected by neonicotinoid use or how agriculture will respond to neonicotinoid usage restrictions. [E$_{\text{xp\_op}}$]

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Annotated bibliography to accompany:

A restatement of recent advances in the natural science evidence base concerning neonicotinoid insecticides and insect pollinators

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Paragraph numbering corresponds to that in the main document; full references at end. The symbol § (for example §16) is used to indicate the paragraph number in Godfray *et al.* (2014) where the same subject was treated. Website URLs were accessed 10 September 2015.

(a) Introduction and aims

(A.1) This document updates Godfray *et al.* (2014).

(A.2) (§1) European Union policy on pollinators and neonicotinoids is described at http://ec.europa.eu/food/animals/live_animals/ bees/pesticides/index_en.htm. Judging by press reports, 120-day derogations have been granted by a number of countries (including for oilseed rape (canola) in Finland, Denmark and Estonia and for maize in Romania, Bulgaria & Serbia) and rejected or withdrawn in others (including Germany and until recently the UK). The UK government approved a limited derogation in July 2015 (http://www.nfuonline.com /news/latest-news/nfu-comment-on-neonicotinoid-distribution), but full details are not yet available. We are not aware of a database listing successful and unsuccessful derogation applications. From July 2015 a policy aimed to significantly reduce usage of neonicotinoid seed coatings on maize (corn) and soy will come into effect in the province of Ontario (Canada) (http://www.ontario.ca/ environment-and-energy/neonicotinoid-regulations). The stated aim is to "reduce the number of acres planted with neonicotinoid-treated corn and soybean seed by 80 per cent by 2017" [from 2015 levels]. Farmers seeking to use neonicotinoid treated seed for these crops will need to provide evidence of a demonstrated pest problem.

(A.3) (§2) Unchanged from Godfray *et al.* (2014).

(b) Pollinators and neonicotinoid insecticides

(A.4) (§4-§11) Simon-Delso *et al.* (2015) provide an extensive review of the history of neonicotinoids, their discovery, mode of action, metabolism (in animals, plants and the environment) and their growing share of the insecticide market. Casida and Durkin (2013) is a general review of neuroactive insecticides. There have also been recent studies of the effect on pollinators of using neonicotinoid sprays on insect pests of turf grass Larson *et al.* (2013), Larson *et al.* (2014), Larson *et al.* (2015). Shao *et al.* (2013) review the development and application of neonicotinoids in China.

(c) Exposure of pollinators to neonicotinoid insecticides

(A.5) (§13-§14) Our estimates for benchmark concentrations of neonicotinoids that pollinating bees are likely to encounter when foraging on crops grown from treated seeds (but not contaminated by dust) are based on Blacquière *et al.* (2012). The

European Food Safety Authority comes to similar conclusions using a different methodology (considering different recommended field application rates) for example for imidacloprid in oilseed rape they estimate 1.59 - 8.35 ng g^{-1} in nectar and 1.56 - 8.19 ng g^{-1} in pollen European Food Safety Authority (2013b, p.18) see also European Food Safety Authority (2013c), European Food Safety Authority (2013a). Bonmatin *et al.* (2015) describe in detail the uptake and movement of neonicotinoids through plants, including the process of guttation (exudation of xylem fluid from the leaves of some plants), and tabulate residue levels in pollen and nectar from different treated crops. They find great variability in range, means and maximum doses (though some of their high figures involve contamination through dust, see next paragraph).

(A.6) (§15) Exposure of pollinators and other non-target organisms to contaminated dust from seed-planting machines is reviewed by Bonmatin *et al.* (2015) and by Krupke and Long (2015); despite attention by regulators they consider it a likely cause of environmental contamination, in particular when best practice is not followed. Cutler *et al.* (2014a) discuss recent incidents of bee mortality involving contaminated dust (chiefly from planting maize) in Canada (also summarized by Health Canada (2014)) though they note that these are declining in number. Stewart *et al.* (2014) found cases of neonicotinoids in the tissues of wildflowers around fields in the mid-southern USA immediately after planting (with maize, cotton & soybean) that they attribute to contaminated dust (23% samples positive; average [maximum] 10 [257] ng g^{-1}). Rundlöf *et al.* (2015), in an experiment described more fully in paragraph (A.26), find plants in margins around fields with neonicotinoid seed-treated oilseed rape had higher levels of clothianidin (1.2 ± 0.8 v 0 ng g^{-1}) in flowers and leaves immediately after sowing compared with untreated crops. The levels in wildflowers around treated crops remained approximately the same two weeks after sowing though at that time measurements were not taken around untreated crops. See also Heimbach *et al.* (2014); Samson-Robert *et al.* (2014).

(A.7) (§16) Bonmatin *et al.* (2015) review the movement of neonicotinoids through soil and water bodies, and toxicity to soil and aquatic invertebrates; see also de Perre *et al.* (2015), Jones *et al.* (2014), Schaafsma *et al.* (2015). Pisa *et al.* (2015) include an extensive review of the effects of neonicotinoids on non-target invertebrates. Barbieri *et al.* (2013) show differential sublethal effects on non-target arthropods (ants) and propose that neonicotinoids could affect community structure. Douglas *et al.* (2015) found evidence that slugs eating soya beans grown from seeds coated with thiamethoxam contained sufficient neonicotinoid to harm the predatory beetles that fed on them, so impairing biological control, and Frewin *et al.* (2014) found

negative effects of neonicotinoids on soya bean aphid parasitoids. Different effects in the aquatic environment are discussed by Anderson *et al.* (2015), Colombo *et al.* (2013), Daam *et al.* (2013), Hayasaka *et al.* (2013), Main *et al.* (2014), Morrissey *et al.* (2015), Pisa *et al.* (2015), Smit *et al.* (2015), van Dijk *et al.* (2013), Vijver and van den Brink (2014). Gibbons *et al.* (2015) review the effects of neonicotinoids on wild vertebrates, while Hallmann *et al.* (2014) argue that neonicotinoids are indirectly responsible for reductions in the density of insectivorous birds in Holland.   For a debate over the interpretation of such imidacloprid aquatic toxicity data in the Netherlands see van Dijk *et al.* (2013) and Vijver and van den Brink (2014).

(A.8) (§18) The study of bee behavioural responses to neonicotinoids was by Kessler *et al.* (2015), see also the commentary on this work by Raine and Gill (2015). For both honeybees and bumblebees thiamexotham and imidacloprid stimulated increased relative consumption of contaminated food sources at field realistic doses. This was despite imidacloprid consistently reducing total consumption in bumblebees (thiamexotham and clothianidin reduced total consumption in bumblebees and honeybees only at the higher concentrations).   In a different study, Easton and Goulson (2013) found that very low doses (1 ng g^{-1}) of imidacloprid in insect traps (yellow pan traps) led to lower catches of pollinating flies and beetles, though how this observation relates to pollinators foraging in the field is not clear.

(A.9) (§20) Rundlöf *et al.* (2015) placed colonies or nests of bees adjacent to oilseed rape fields in Sweden (see also (A.26)) and found this plant species composed 53-63% of pollen collected by honeybees, 75-88% by bumblebees (*Bombus terrestris*), and 35% for a solitary bee (*Osmia bicornis*). Cutler *et al.* (2014b) working in Southern Ontario found 88% of pollen loads at some times to be composed of oilseed rape pollen when honeybee colonies were placed in the middle of fields. Garbuzov *et al.* (2015) decoded honeybee waggle dances to deduce limited foraging of rural bees on oilseed rape in southern England (most foraging was within 2 km of the hive), a conclusion supported by pollen sampling (oilseed rape constituted up to 14% by weight). Some data on other bee species in Holzschuh *et al.* (2013). Stanley *et al.* (2013) and Stanley and Stout (2014) regularly found three species of bumblebees (*B. terrestris*, *B. lucorum* and *B. cryptarum*) foraging in oilseed rape fields in Ireland. Overall 35% of all flower visits to oilseed rape were made by bumblebee species, 32% from hoverflies, 17% from honeybees, 12% from other flies and about 2.5% from solitary bees.

(A.10) (§21) Authors.

(d) Laboratory studies of lethal and sublethal effects of neonicotinoids

(A.11) (§22-§27) Review by Pisa *et al.* (2015); see also Rondeau *et al.* (2014) on chronic exposure. Fairbrother *et al.* (2014) review the risks to honeybees of neonicotinoids and Johnson (2015) is a general review of honeybee toxicology paying particular attention to the spectrum of compounds and combination of compounds that the insects are exposed to. Tome *et al.* (2015) assess imidacloprid toxicity in a species of meliponine (stingless) bee, an important but under-studied group of tropical pollinators. Fryday *et al.* (2015) provide an exhaustive annotated list of publications discussing adverse effects on pollinating bees of imidacloprid, clothianidin and thiamexotham. Lundin *et al.* (2015) survey studies of the effects of neonicotinoid on bees pointing out their geographical and taxonomic biases [this study

was published while our work was in press and hence is only briefly mentioned here].

(A.12) (§25) In the laboratory neonicotinoids increase acetylcholinesterase activity and Boily *et al.* (2013) found that honeybees from hives placed next to conventional crops had higher activity of this enzyme than those located by organic crops or uncultivated ground, though whether neonicotinoids were responsible could not be established. Hatjina *et al.* (2013) found that newly emerged honeybees fed food contaminated with low doses of imidacloprid (at 2-3 ng g^{-1}) developed smaller hypopharyngeal glands and had perturbed patterns of abdominal ventilation ("breathing"), while cytological effects of sublethal exposure to thiamethoxam were studied by Oliveira *et al.* (2014). Henry *et al.* (2014) showed that relatively high, but sublethal, doses of neonicotinoids have effects on honeybee foraging in natural environments that are influenced by weather and landscape structure. Fischer *et al.* (2014) observed impaired honeybee navigation after insects had received high sublethal oral doses (per bee) of 2.5 ng clothianidin or 7.5 & 11.5 ng imidacloprid. Sandrock *et al.* (2014b) found that field-realistic sublethal doses of thiamethoxam and clothianidin reduced short-term honeybee colony performance, but colonies recovered and there was no effect on overwintering fitness. However, impaired colony growth associated with queen failure and reduced swarming was observed in the following spring (an effect of honeybee genetic background was also observed). Exposing honeybees to contaminated food solutions (10ng g^{-1} imidacloprid, thiamethoxam or clothianidin for 24hr) affected some but not all motor functions Williamson *et al.* (2014). Asian (or Eastern) honeybees (*Apis cerana*) fed relatively high levels of imidacloprid (34 ng g^{-1}), showed poorer predator avoidance and reduced foraging performance Tan *et al.* (2014). The same species fed much lower doses of imidacloprid (0.1 ng per bee) as adults showed impaired olfactory learning, as did adults developing from larvae exposed to doses of 0.24 ng per individual (there was no effect on mortality) Tan *et al.* (2015). Elston *et al.* (2013) exposed queenless microcolonies of bumblebees (*B. terrestris*) to supplementary diets containing low (1 ng g^{-1}) or high (10 ng g^{-1}) concentrations of thiamexoham (plus a control). Fewer wax cells were produced in both treatments and no larvae were produced at the higher exposure. Scholer and Krischik (2014) provided bumblebee colonies (*B. impatiens*) in greenhouses with relatively high doses (≥ 10ng g^{-1}) of imidacloprid and clothianidin and observed a variety of sublethal and lethal consequences. Moffat *et al.* (2015) found that chronic field-realistic low doses (~2 ng g^{-1}) of clothianidin and imidacloprid accumulated in the brains of bumblebees (*B. terrestris*) and led to mitochondrial dysfunction in neurons (that was exacerbated by the presence of acetylcholine). This provides a mechanism that may explain the effects of neonicotinoids on navigation and raises the possibility that actively foraging insects (in which higher levels of acetylcholine will be present) may have greater susceptibility to sublethal exposure (see also (A.22)). Chronic sublethal dietary exposure of a solitary bee (*O. bicornis*) to low doses of thiamexoham (2.87 ng g^{-1}) and clothianidin (0.45 ng g^{-1}) led to large reductions in lifetime reproductive success Sandrock *et al.* (2014a).

(A.13) (§26) Archer *et al.* (2014) found protein-fed honeybees better able to withstand nicotine stress (which the authors interpret as implying stressed bees may be more susceptible to neonicotinoids). Doublet *et al.* (2015) and Retschnig *et al.* (2014) found that thiacloprid (a neonicotinoid, though not one used frequently as a seed treatment) elevated larval mortality due to

Black Queen Cell Virus and adult mortality due to *Nosema ceranae* (a microsporidian parasite) respectively. Fauser-Misslin *et al.* (2014) fed laboratory colonies of bumblebees syrup contaminated with low doses of thiamethoxam (4 ng g^{-1}) and clothianidin (1 ng g^{-1}) over a nine-week period, a relatively long period of chronic exposure. The treatments were crossed with exposure to the bumblebee pathogen *Crithidia bombi*. Reductions in worker longevity and colony productivity were observed in the neonicotinoid treatments, but they were not exacerbated by the presence of the pathogen. In contrast, queen longevity was significantly reduced only in the combined neonicotinoid and pathogen treatment. Results from a similar crossed design study, using a pyrethroid insecticide (λ-cyhalothrin) and the same parasite (*C. bombi*), found no effect of insecticide exposure on worker longevity, susceptibility to parasitic infections or colony development, but did lead to a reduction in worker body mass Baron *et al.* (2014). Thompson *et al.* (2014) studied synergistic effects of neonicotinoids and routinely used fungicides. Using field realistic (but worst case) doses of four fungicides (flusilazole, propiconazole, tebuconazole and myclobutanil) the impact on the LD$_{50}$ of four neonicotinoids (thiamethoxam, clothianidin, imidacloprid and thiacloprid) was examined via contact and oral doses. Significant (though not testing for multiple comparisons) synergistic effects on LD$_{50}$ were found in two of the 32 combinations tested (contact doses of thiamethoxam with tebuconazole and oral doses of clothianidin with tebuconazole). In a field experiment Moffat *et al.* (2015) (see (A.22)) found no significant synergistic effects of the organophosphate chlorpyrifos and imidacloprid.

(A.14) (§27a) Arena and Sgolastra (2014) compared the LD$_{50}$s of a very broad range of pesticides including imidacloprid (ten studies) and thiamethoxam (four studies) on different bee species relative to the honeybee. For imidacloprid there was a wide range of relative susceptibilities (approximately equal numbers of studies found the honeybee to be more or less susceptible than other bee taxa) while the fewer studies of thiamethoxam all found honeybees had higher LD$_{50}$s (i.e. were less susceptible).

(A.15) (§28) Authors.

(e) Neonicotinoid residues observed in pollen, nectar & wax in the field

(A.16) (§29-§31) Bonmatin *et al.* (2015) reviewed translocation of neonicotinoids to nectar and pollen and the likely concentrations there. They provide tables of estimates of neonicotinoid incidence and concentrations from studies we previously reviewed plus some new material. See also Krupke and Long (2015). Sanchez-Bayo and Goka (2014) reviewed data for the concentration of pesticides in nectar, pollen and wax. They develop an index of risk based on (i) frequency of presence for residues; (ii) average and maximum concentrations when present; and (iii) published toxicity through different exposure regimes (contact or ingestion, acute or chronic). Using heterogeneous data from all geographical regions they conclude that clothianidin, imidacloprid and thiamethoxam rank highly in their potential risks to honeybees and bumblebees compared to other pesticides. See also Kasiotis *et al.* (2014). Pohorecka *et al.* (2013) found high levels of clothianidin in pollen collected by honeybees from hives placed next to maize fields in Polish agricultural landscapes irrespective of the insecticide regime applied to the crop. Fryday *et al.* (2015) provide an exhaustive annotated list of publications relevant to exposure of pollinating bees to imidacloprid, clothianidin and thiamexotham.

(A.17) (§32) Authors.

(f) Experiments conducted in the field

(A.18) (§33) Issues concerning semi-field experiments chiefly revolve around whether the dose and method of application is relevant to the experience of pollinators in the field. Thus Carreck and Ratnieks (2014) critique the doses used in several of the semi-field experiments, arguing that they are probably higher than bees are likely to experience foraging in farmed landscapes. Issues around field experiments include the length of time bees are exposed to neonicotinoid-treated crops, and what happens to colonies after exposure: for example the realism of removing them to habitats with no risk of further insecticide exposure and the extent to which they are given additional food. In addition, the controls used in field experiments are usually the absence of all insecticides and not the alternative pest management strategy that would be adopted by a farmer. A no-insecticide control tests the absolute effect of neonicotinoids while an alternative pest-management control tests the effect of neonicotinoid restrictions. After this article was in press a study on honeybee colonies around two treated and two control fields in Canada was published by Alburaki *et al.* (2015).

(A.19) Dively *et al.* (2015).

(A.20) Lu *et al.* (2014) estimated that each bee in the neonicotinoid treatment consumed 0.74 ng of insecticide per day. Replication was six colonies per treatment; three of these colonies received syrup made from sucrose mixed with water, the other three colonies were fed high-fructose corn syrup over the study period. The number of frames within each hive occupied by bees was monitored over the subsequent winter. Five out of six control colonies and either two (imidacloprid) or four (clothianidin) out of six colonies in the neonicotinoid treatments survived. From mid-winter control hives were reported to have significantly more occupied frames than insecticide treated hives. The quoted average consumption of neonicotinoid insecticides is 3-12 times higher than the worst-case nectar ingestion rates calculated in §22e; the assumption of a constant 50,000 bees per colony is high and were it lower the consumption rate would be even greater. Foraging bees, which consume more food, will also experience higher exposure. We were not able to understand the statistical analysis from the description in the paper and after discussion with the authors requested sight of the original data (May 28th 2014) which has not yet been granted.

(A.21) Gill and Raine (2014) reported new analyses of the semi-field experiment on 40 bumblebee colonies reported in Gill *et al.* (2012); see §37 for discussion of insecticide application technique and relevance to field concentrations.

(A.22) Moffat *et al.* (2015) found significant effects of imidacloprid on the number of live bees and healthy brood cells, the total bee mass in the nest and the final mass of the nest, but not on the average mass of live bees. The imidacloprid treatment was crossed with a second treatment involving the potential antagonist chlorpyrifos (an organophosphate), but this had no statistically significant extra effects on colony performance. Six colonies (placed three to a box) were assigned to each of the four treatments. The paper also reported studies of the physiological effects of low (~2ng g^{-1}) concentrations of imidacloprid on bumblebee brain function (see (A.12)).

(A.23) (§38) Reanalysis of Thompson et al (2013; http://fera.co.uk/ccss/documents/defraBumbleBeeReportPS2371V4a.pdf) by Goulson (2015) which differed in statistical methodology, treatment of low concentration data values, and

exclusion of points considered outliers. Commenting on the experiment in §38a we said "the experimental design, in particular the lack of replication at field level and absence of a clear effect of treatment, allows only limited inference about the effects of neonicotinoids in the field" which we consider still applies.

(A.24) The plots used by Cutler *et al.* (2014b) were small (2 ha) compared to most commercial fields, and the potential pesticide exposure period was less than likely to occur under typical conditions. Most (88%) pollen collected by the honeybees in the first week was oilseed rape but in the second week this fell to 46%. For each colony they measured colony weight gain, pollen collected, honey yield, number of adults and number of sealed brood cells, as well as *Varroa* mites per bee, *Nosema* infection and number of dead bees. Colonies, especially at first, foraged predominantly on the spring-sown oilseed rape (88% in first week, 46% in second) where exposure in pollen was estimated as ~0.5-2 ng g^{-1}. Clothianidin concentrations in pollen collected by bees in treated fields was low, 0.84 ± 0.49 ng g^{-1}, and in control fields three-times less but non-zero at 0.24 ± 0.44 ng g^{-1} (an analysis that forced confidence limits to be non-negative would have been preferable). Overwintering success and a range of other endpoint measures did not significantly differ between treated and control hives. A statistical power analysis of the experiment was not reported.

(A.25) The Cutler and Scott-Dupree (2014) study used fields planted by commercial farmers and hence was not strictly a controlled experiment and some potentially confounding factors were noted. For example, the potential pesticide exposure period was less than likely to occur under typical conditions,. For example, the neonicotinoid seed-treated maize produced pollen earlier than the organic maize, and different neonicotinoid (involving clothianidin and/or thiamethoxam) treatments were applied in the four non-organic treatments. Neonicotinoid levels reported in maize pollen (0.1 − 0.8 ng g^{-1} in treated fields) are low compared to typical concentrations. Colonies were moved after 5-6 days to a neonicotinoid free environment. A statistical power analysis of the experiment was not reported.

(A.26) The Rundlöf *et al.* (2015) paper in *Nature* was accompanied by a commentary by Raine and Gill (2015). The neonicotinoid was applied as the formulation Elado (Bayer) which also contains a pyrethroid β-cyfluthrin; treatment and control sites received a fungicide seed treatment. Wild bees were scarcer in the oilseed rape crop and adjacent uncultivated field borders of treated fields, the analysis controlling for a significant association between flower cover and bee density. Solitary bee nesting success was estimated by placing commercially reared *Osmia bicornis* cocoons in the fields, and observing whether emerging females constructed brood cells in supplied nest traps. None of the female solitary bees in treated fields constructed brood cells, whilst some (but not all) females in 6 of 8 untreated fields did). Bumblebee colony growth and queen production was measured by placing *B. terrestris* colonies adjacent to fields, and honeybee colony performance (number of adult bees) by putting hives at each site. A statistical power analysis indicated that the experimental design would detect a 20% effect on honeybee colony performance, with a probability of 0.8. All pollinator species were shown to feed on oilseed rape, and nectar and pollen collected by honeybees had higher concentrations of clothianidin in treated fields than control fields (10.3 ± 1.3 v 0.1 ± 0.1 ng g^{-1} for nectar; 13.9 ± 1.8 v 0.0 ng g^{-1} for pollen) and similarly for nectar collected by bumblebees (5.4 ± 1.4 v 0.0 ng g^{-1}). The non-systemic β-cyfluthrin was not detected.

(A.27) (§40) Authors.

(g) Consequences of neonicotinoid use

(A.28) (§41) The model, BEEHAVE, is described in Becher *et al.* (2014). They illustrate how it might be used to study neonicotinoid exposure by including the effects of thiamethoxam on forager mortality reported by Henry *et al.* (2012) (as discussed in §35, the doses used are higher than likely to be encountered in the field). They show the consequences of exposure will be greater in poor quality environments and may take several years to become apparent. Bryden *et al.* (2013) describe a model in which sublethal stress affects individual behaviour with knock-on effects for bumblebee colony performance. They show that chronic exposure to sublethal stress can result in colony failure and that model predictions accurately fit data collected from real *B. terresrtris* colonies exposed to imidacloprid under laboratory conditions.

(A.29) Budge *et al.* (2015) provide the data in their paper allowing a reanalysis. They treat nine regions and six time points (with some missing values giving 52 data points). Fitting region and then imidacloprid use to honeybee colony loss, they obtain a significant effect of the insecticide. The effect is weak, explaining 8% of the variation of the data (5% or less if weather covariates are included). If year is added to the model the association with imidacloprid is no longer significant and the variation explained is near zero suggesting that the result is due to a correlation between annual patterns of imidacloprid use (which rise and then fall over this period as neonicotinoids are introduced and then imidacloprid is superseded) and honeybee in-season losses (which show the same general pattern, being highest mid-decade). The critical issue is whether this is causal or correlative. The statistical test that finds the significant association with imidacloprid treats all regions as statistically independent (giving 42 degrees of freedom). If, as is likely, the regional data are affected by unknown common hidden variables (for example widespread weather patterns not captured by the proxies used in the analysis) then the real degrees of freedom will be lower (between 6 and 42) as will the power of the test and the significance of any association.

(A.30) (§42) Kleijn *et al.* (2015) is a meta-analysis of 53 studies of crop pollinators from around the world designed to assess the contribution of different species to crop pollination. They also calculated the economic contribution of wild bees to crop production using the production value method.

(A.31) (§43) Ollerton *et al.* (2014) used a unique database from the Bees, Wasps & Ants Recording Society (BWARS) in the UK to study the temporal distribution and correlates of the 23 recorded extinctions of pollinating bees and wasps. Senapathi *et al.* (2015) repeated historical surveys of land-use and related it to BWARS wild bee and wasp data concluding that bee communities have become less species-rich and more similar over time. These changes were correlated with changes in land-use (and negatively with arable expansion). Kerr *et al.* (2015) analysed 423,000 observation records of 67 bumblebee species over a 110 year period in North America and Europe to build statistical models to test whether range shifts were explained by climate change, land use change or pesticide use. Across both continents, bumblebees were found not to be tracking climate change by expanding their northern limits; however, they were retreating from their southern limits. Shifts in bumblebee ranges were not correlated with changes in land use or pesticide usage, including neonicotinoids, over the same period. Pesticide data was only

available for North America and so was not tested for Europe. The available data used to test whether changes in bumblebee range limits were associated with neonicotinoid use and land-use change were measured at relatively coarse scale. The impacts of neonicotinoids in particular, should they occur, would be expected to affect populations and diversity in subtle ways and at finer scales; dramatic changes in population size could occur within a species distribution range whether or not the overall range is expanding or contracting. Therefore the limitations of the available neonicotinoid data mean that the lack of an effect of neonicotinoid use on range limits should be carefully considered in any inference about neonicotinoid impacts on local abundance, diversity, population trends or individual bee health. Burkle *et al.* (2013) showed degradation of plant-pollinator network structure and loss of species and pollination function at a site in Illinois, USA, was related to global change over 120 years. Scheper *et al.* (2014) analysed pollen loads collected from museum specimens of wild bees, together with wild bee and plant distribution data over time. They concluded that bee declines in the Netherlands were mainly driven by loss of preferred food-plants. Szabo *et al.* (2012) analysed population trends in three species of North American bumblebee and concluded that pesticide use (including neonicotinoids) and habitat loss are unlikely to be major causes of observed declines. Their proxy for insecticide use in their analysis was criticized by Stevens and Jenkins (2013). A revised analysis Colla *et al.* (2013) also found no evidence for neonicotinoid use being correlated with bumblebee decline though the authors caution that the analysis is not definitive. Landscape context may buffer the impact of neonicotinoids on wild bees Park *et al.* (2015). Goulson *et al.* (2015a) review the reasons for the decline of pollinator species and conclude that multiple interacting factors, including pesticides, are responsible. In correspondence arising from the paper the quality of data and need for monitoring was debated Ghazoul (2015), Goulson *et al.* (2015b).

(A.32) (§44) Updated data for Europe (http://ec.europa.eu/food/animals/live_animals/bees/docs/bee-report_en.pdf, http://www.coloss.org/announcements/losses-of-honey-bee-colonies-over-the-2013-14-winter; http://www.coloss.org/announcements/losses-of-honey-bee-colonies-over-the-2014-15-winter-preliminary-results-from-an-international-study) and for the USA Steinhauer *et al.* (2014), Lee *et al.* (2015) and Canada (http://www.capabees.com/ category/extension/overwintering-losses/) are now available. The European data (from before the neonicotinoid restrictions) overall showed the lowest overwintering losses in 2013/2014 since the survey began in 2007.

(A.33) (§45) Unpublished results on the UK Crop Monitor website http://www.cropmonitor.co.uk/wosr/surveys/wosrPestAssLab.cfm?year=2014/2015&season=Spring show comparatively higher levels of beetle pests on oilseed rape in spring 2015, compared to previous years, in some geographical areas but not others. The recent UK oilseed rape study is Budge *et al.* (2015).

(A.34) (§46) Authors.

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