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Risk to pollinators from anthropogenic electro-magnetic radiation (EMR): evidence and knowledge gaps

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Discussion

Risk to pollinators from anthropogenic electro-magnetic radiation (EMR): Evidence and knowledge gaps

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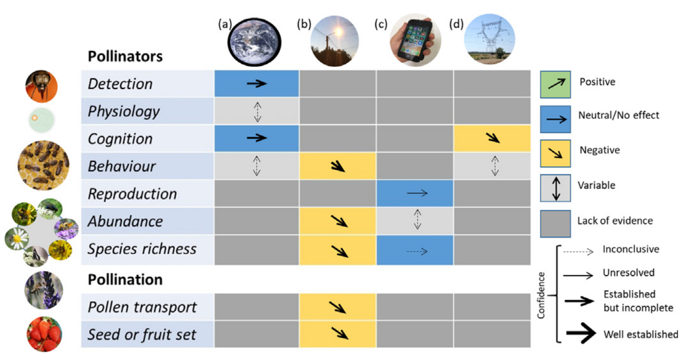
HIGHLIGHTS

- Anthropogenic electromagnetic radiation (light, radiofrequency) is perceived to threaten pollinators and biodiversity.
- Potential risks are artificial light at night (ALAN) and anthropogenic radiofrequency electromagnetic radiation (AREMR).
- We assessed the quantity and quality of evidence, and the level of consensus, to distil key messages for science and policy.
- ALAN can alter pollinator communities and functions, although this remains to be well established.
- Evidence of AREMR impactsis inconclusive due to a lack of high quality, field-realistic studies.
- Whether pollinators and pollination face a threat from the spread of ALAN or AREMR remains a major knowledge gap.

GRAPHICAL ABSTRACT



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ABSTRACT

Worldwide urbanisation and use of mobile and wireless technologies (5G, Internet of Things) is leading to the proliferation of anthropogenic electromagnetic radiation (EMR) and campaigning voices continue to call for the risk to human health and wildlife to be recognised. Pollinators provide many benefits to nature and humankind, but face multiple anthropogenic threats. Here, we assess whether artificial light at night (ALAN) and anthropogenic radiofrequency electromagnetic radiation (AREMR), such as used in wireless technologies (4G, 5G) or emitted from power lines, represent an additional and growing threat to pollinators. A lack of high quality scientific studies means that knowledge of the risk to pollinators from anthropogenic EMR is either inconclusive, unresolved, or only partly established. A handful of studies provide evidence that ALAN can alter pollinator communities, pollination and fruit set. Laboratory experiments provide some, albeit variable, evidence that the

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honey bee *Apis mellifera* and other invertebrates can detect EMR, potentially using it for orientation or navigation, but they do not provide evidence that AREMR affects insect behaviour in ecosystems. Scientifically robust evidence of AREMR impacts on abundance or diversity of pollinators (or other invertebrates) are limited to a single study reporting positive and negative effects depending on the pollinator group and geographical location. Therefore, whether anthropogenic EMR (ALAN or AREMR) poses a significant threat to insect pollinators and the benefits they provide to ecosystems and humanity remains to be established.

1. Pollinators and pollination under threat

Global insect biodiversity is under threat from multiple anthropogenic drivers of global environmental change, which in turn jeopardize the many benefits people obtain from this component of nature (Hallmann et al., 2017; IPBES, 2016; Potts et al., 2016; Sánchez-Bayo and Wyckhuys, 2019). Insect pollinators are particularly high on the science and policy agenda worldwide and there exists a comparatively strong evidence base on their values, status and trends, and the threats they face (IPBES, 2016). Known pressures impacting pollinators and pollination services include land-use change, intensive agricultural (and other land) management, use and misuse of pesticides, climate change, pests and pathogens, alien invasive species and potentially interactions between these different drivers (Brown et al., 2016; IPBES, 2016; Vanbergen et al., 2013).

Environmental pollution presents a further potential risk to pollinators and pollination although its impact is much less studied according to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services[1] (IPBES, 2016). One form of pollution that presents a potential risk to wildlife and that has grown significantly since the mid-20th century (Fig. 1) is the global spread of anthropogenic electromagnetic radiation (EMR: radio waves, microwaves, infrared, visible light, ultraviolet, X-, and gamma radiation) (Balmori, 2015; Bandara and Carpenter, 2018; Grubisic et al., 2018; Russell, 2018). With a focus on human health, the WHO has evaluated the risk (e.g. the International EMF project since 1996[2]) from non-ionizing anthropogenic EMR (up to 300 GHz). Although finding no major public health concerns, the WHO acknowledges uncertainties around chronic exposure and new technologies[2]. Currently, neither the WHO nor the OECD with its economic and development focus (OECD, 2012), have considered the current or future indirect risks from anthropogenic EMR to the natural environment, which provides diverse values and benefits to humankind.

The global proliferation of both artificial light at night (ALAN) and anthropogenic radiofrequency electromagnetic radiation (AREMR) utilised in mobile and smart wireless technologies (Fig. 1) is ongoing with increasing urbanisation and the worldwide launch of next generation wireless technologies e.g. 5G, smart grids and the 'Internet of Things' (Bandara and Carpenter, 2018; Bin Zikria et al., 2018; Macgregor et al., 2015; Russell, 2018). What remains unclear is the extent that ALAN or AREMR represent a threat to insect pollinators and the benefits they provide to nature and humankind (Fig. 2).

2. Artificial light at night (ALAN)

The potential risk from ALAN to nocturnal pollinators and pollination was noted by the academic community (Macgregor et al., 2015) and mentioned in the IPBES assessment of pollinators and pollination as "*a driver clearly affecting nocturnal species and growing in importance due to urbanization*". The IPBES also noted that compared to other drivers "*Its effect is still scarcely studied*" and called for further studies "*to evaluate the extent of light pollution effects on nocturnal pollinators*" (IPBES, 2016). Since this global assessment, further studies have been published that show how ALAN can disrupt pollinator communities and plant reproduction. Knop et al. (2017) demonstrated by field experiment how artificial light modified the architecture of nocturnal plant-pollinator communities and reduced visitation rates to plants by 62% leading to a 13% drop in the fruit set of a focal plant species (*Cirsium oleraceum*, Asteraceae) (Knop et al., 2017). Other recent studies have demonstrated how artificial street lighting reduces local abundance and species richness of moths and their rates of feeding and pollen transport (Grubisic et al., 2018; Macgregor et al., 2017; van Langevelde et al., 2017). Together such studies illustrate the potential for ALAN to modify pollinator foraging and pollination function in ways that have the capacity to jeopardize pollinator populations, either directly or indirectly. Moreover, analysis of combined nocturnal and diurnal plant-pollinator networks suggested that these nocturnal impacts of light pollution transmitted to the diurnal network through trophic interactions connecting nocturnal to diurnal species (Knop et al., 2017). This highlights the potential for the effects of ALAN to exacerbate the overall anthropogenic pressure on diurnal pollinators (Potts et al., 2016; Vanbergen et al., 2013). Therefore, there is emerging, albeit incomplete, evidence that ALAN represents a potentially growing impact on pollinators and pollination as global urbanisation proceeds apace (Figs. 2 & 3).

3. Anthropogenic radiofrequency electromagnetic radiation (AREMR)

Campaigning voices continue to perceive and call for the threat from anthropogenic EMR to both human health[3] and wildlife[4] to be recognised and evaluated. Aside from ALAN, the IPBES report (IPBES, 2016; Potts et al., 2016) did not consider other sources and wavelengths of anthropogenic EMR. This was because it was judged at that time (publications up to July 2015) there was insufficient data for an evidence assessment, with only a few studies showing how bees utilise magnetic fields (Clarke et al., 2013; Gould et al., 1978; Hsu and Li, 1994) and fewer still on potential effects of AREMR (Favre, 2011; Greenberg et al., 1981). Similarly, AREMR (and ALAN) were not identified as a risk in a 2016 horizon scan of future threats and opportunities for pollinators and pollination (Brown et al., 2016). Moreover, likely due to the continuing lack of scientific publications, anthropogenic EMR as a driver of biodiversity change remained unassessed by the IPBES during its most recent regional (2018) and global (2019) assessments.[5] However, a 2018 horizon scan focussed on biodiversity conservation, natural capital and ecosystem services pointed to the potential, but unstudied, risk to wildlife of non-ionizing radiation from 5G mobile phones and wireless transmission infrastructure (Sutherland et al., 2018).

Therefore, the perception remains that AREMR (in addition to ALAN) poses a current and growing risk to pollinators and pollination (Balmori,

[1] https://www.ipbes.net/
[2] https://www.who.int/peh-emf/project/en/
[3] https://www.emfscientist.org/
[4] https://www.buglife.org.uk/news-and-events/news/could-our-obsession-with-mobile-technology-destroy-wildlife
[5] https://www.ipbes.net/assessment-reports

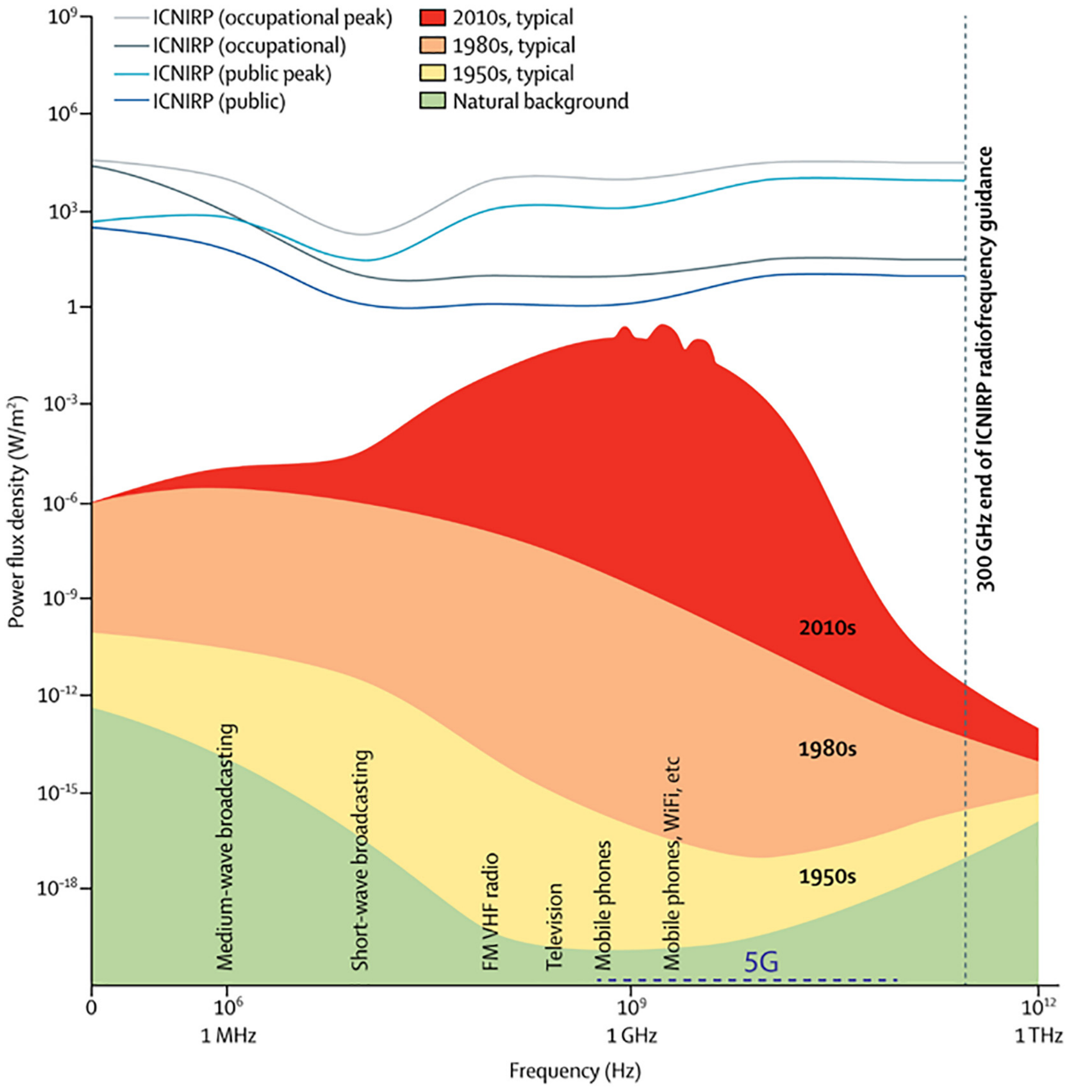

Fig. 1. Typical maximum daily exposure to radiofrequency electromagnetic radiation from anthropogenic and natural power flux densities in comparison with International Commission on Non-Ionizing Radiation Protection (ICNIRP) safety guidelines. Sources of anthropogenic radiofrequency electromagnetic radiation levels are illustrated for different periods. Source: Bandara P, Carpenter DO. Planetary electromagnetic pollution: it is time to assess its impact. The Lancet Planetary Health 2018; 2: e512–e514. Reproduced under license from Elsevier.

2015). Studies have shown the honey bee (*Apis mellifera*) is able to detect magnetic fields physiologically (Gould et al., 1978; Hsu and Li, 1994; Kirschvink and Kirschvink, 1991; Lambinet et al., 2017; Liang et al., 2016) and potentially use this capacity for orientation, navigation and foraging (Fig. 2). Furthermore, bees use electric fields of the same magnitude as commonly encountered AREMR for intraspecific (within hive) and interspecific (plant-pollinator) communication, in the context of foraging on floral resources (Clarke et al., 2013; Greggers et al., 2013). Therefore, there is the possibility that AREMR could disrupt these physiological functions, ultimately affecting bee health and survival.

In October 2016, the EU (H2020) EKLIPSE[6] project (Watt et al., 2019), in response to a request from the UK charity Buglife, organised a foresight activity identifying the state of and gaps in knowledge concerning the emerging issue of anthropogenic EMR (excluding ALAN) impacts on wildlife. This involved a scientific literature search (ISI Web of Knowledge & Google Scholar, completed by July 2017) to gather a representative, but not exhaustive, set of relevant peer-reviewed papers published from 2000 onwards, coincident with the onset of the proliferation of mobile technologies (Fig. 1) (details in Malkemper et al., 2018). A scientific expert working group was convened to assess this evidence (Malkemper et al., 2018) and, following a stakeholder web conference, a summary of the current evidence and knowledge gaps was produced (Goudeseune et al., 2018). Here we summarise and update these reports with assessment of new studies to understand what the evidence base is for a risk to pollinators and pollination from the global spread of AREMR.

The EKLIPSE report confirmed the sparseness of the literature and scarcity of data regarding anthropogenic EMR impacts on wildlife (Malkemper et al., 2018). Of an initial 147 scientific papers or reviews identified, further scrutiny of their relevance to the topic of anthropogenic EMR emissions and its effect (or lack of) on wildlife reduced the list of citations to 82 papers (97 including reviews). These included 39 studies on various invertebrate groups including *Drosophila* fruit flies, beetle or ant species, but also a managed pollinator species (*A. mellifera*) and, in a few cases, wild pollinator communities (Malkemper et al., 2018). Each study was assessed and scored according to their scientific and technical quality (0 = irrelevant or very poor

[6] EKLIPSE is funded to develop a new, self-sustaining support mechanism for evidence-based and evidence-informed policy on biodiversity and ecosystem services by assessing knowledge, research gaps and emerging issues in response to requests from policymakers, civil society and science actors. http://www.eklipse-mechanism.eu/

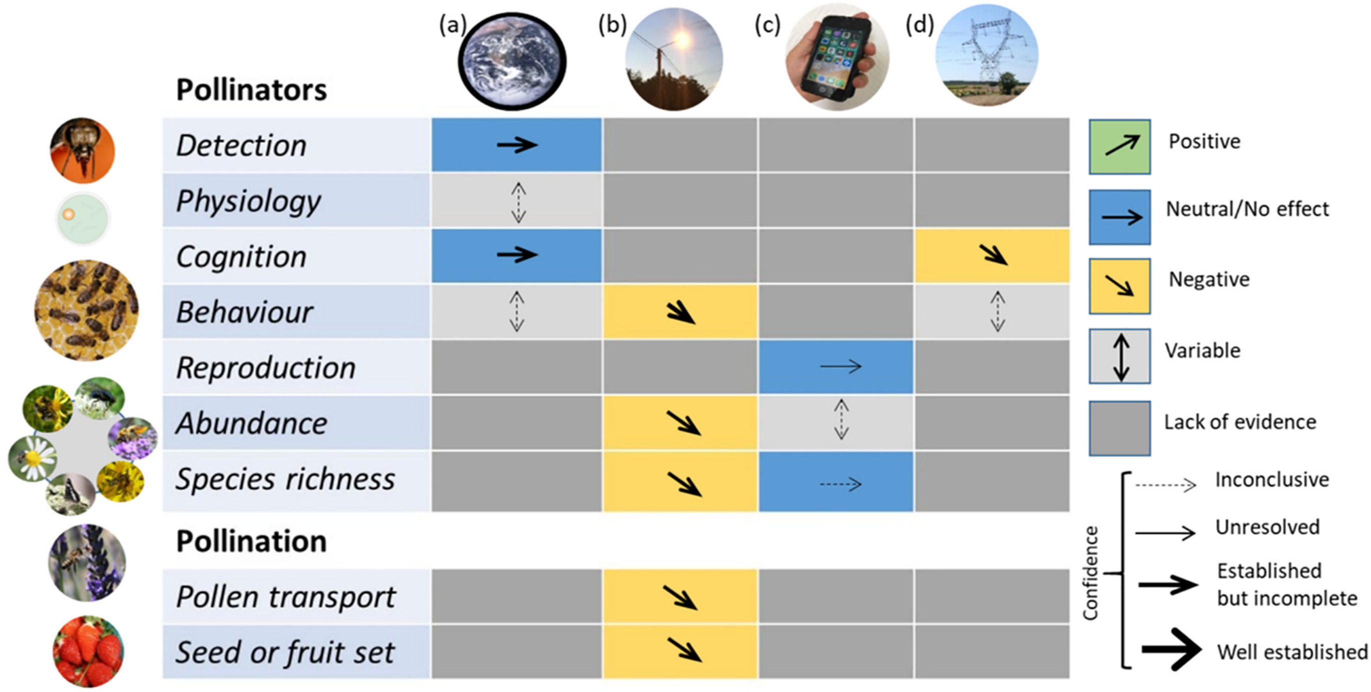

Fig. 2. The level of scientific knowledge about the impact on pollinators and pollination of natural (a) and anthropogenic (b: ALAN; c: mobile; d: electrical infrastructure) sources of electromagnetic radiation. Based on the available evidence from journal publications, the impact on different aspects of pollinator biology and pollination services are assessed as being positive, negative, neutral or variable (idiosyncratic or contrasting). The level of confidence (quantity, quality and consensus) in this evidence is expressed according to the four-box model adopted from the IPBES (see Fig. 3 for details).

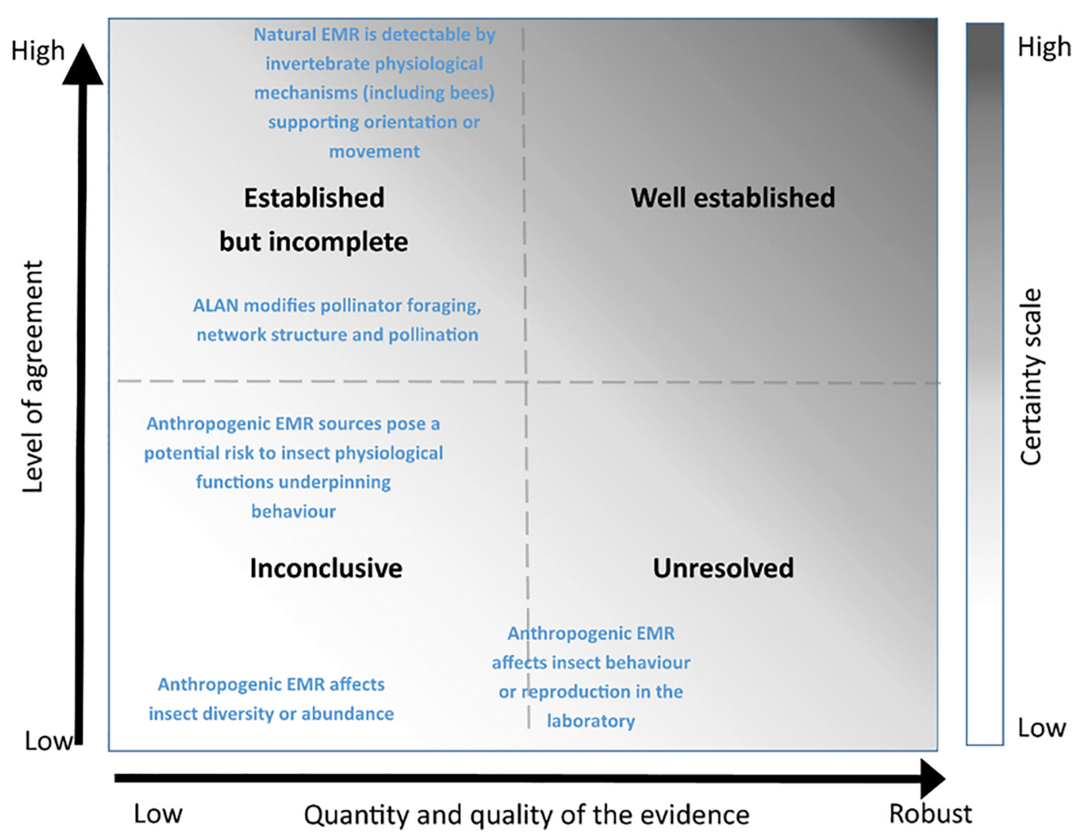

Fig. 3. Position of key messages in relation to the level of confidence (quantity, quality and consensus) in the evidence base using a four-box model for the qualitative communication of certainty (IPBES, 2016). Confidence increases towards the top-right corner as shown by the increased strength of shading. Terms are: **Well established** - comprehensive meta-analysis or other synthesis or multiple independent studies that agree; **Established but incomplete** - general agreement although only a limited number of studies exist but no comprehensive synthesis and/or the studies imprecisely address the question; **Unresolved** - multiple independent studies exist but conclusions do not agree; **Inconclusive** - limited evidence, recognising major knowledge gaps.

science; 1 = minimal with only some utility; 2 = medium - some limitations or caveats, 3 = excellent). Here, we also distilled key messages for scientists and decision-makers to evaluate our assessment of the published evidence and the level of the potential problem. To communicate the level of certainty in knowledge, we attached a degree of confidence to each key message using a qualitative 'four-box model' (adopted from the IPBES, 2016) that shows the assessment of the quantity, quality and level of expert consensus on the evidence (Fig. 3).

3.1. Acute exposure to EMR in laboratory experiments

The highest quality research (score = 3) assessed in the EKLIPSE report were laboratory experiments testing the fundamental biological responses of the bumblebee *Bombus terrestris* or other model insect species (i.e. *Drosophila* flies, locusts, plant-hoppers) to naturally occurring electromagnetic fields and their exclusion or experimentally-imposed electromagnetic treatments closely mimicking nature. These few scientifically rigorous laboratory experiments showed how insects can detect and may orientate using electromagnetic fields and the effects, or lack of, on behaviour, cell development, and physiological function (Bae et al., 2016; Sutton et al., 2016; Tomanová and Vácha, 2016; Wan et al., 2014) (Fig. 2). Of these experiments, there was little evidence of exposure to EMR leading to damage or effects on individual development, or reproduction in these model invertebrate species (Bae et al., 2016; Wan et al., 2014; Wyszkowska et al., 2016; Zhang et al., 2016). The most convincing finding was, as with birds (Engels et al., 2014) and mammals (Malkemper et al., 2015), that the magnetic sense of invertebrates appears to be affected by AREMR in the MHz-range (Tomanová and Vácha, 2016; Vácha et al., 2009), although the extent to which insects are dependent on their magnetic sense for successful navigation remains unknown. Crucially, whilst providing some mechanistic basis for testing hypothesis on EMR impacts, these laboratory studies do not provide any evidence about impacts of AREMR on invertebrates in ecosystems. Moreover, the effects observed tended to be complex, variable in direction or effect size, and only sometimes adverse (Fig. 2).

Since publication of the EKLIPSE report, Shepherd et al. (2018) produced an appropriately controlled and analysed set of laboratory experiments testing the impact of experimental AREMR treatments on the cognitive and motor abilities of the honey bee (*Apis mellifera*). They exposed honey bees to extremely low frequency electromagnetic fields (50 Hz) replicating modelled estimates of fields generated by overhead power transmission cables at ground level (range 20–100 μT EMF) or proximate to the conductor (7000 μT EMF) (Shepherd et al., 2018). Acute laboratory exposure to levels of 20 to >100 μT EMF had a clear negative impact on worker bee learning and memory as measured with a standard test (Proboscis Extension Reflex) (Shepherd et al., 2018). An increase in wingbeat frequency in tethered flight experiments was seen at the highest EMF (7000 μT), but because pollinators mostly forage at ground level it is unlikely that bees or other pollinators would routinely fly close enough to conductors to be exposed to such levels. There were also significant, but relatively weak, deterrence effects on the flight rate and number of feeding worker bee foraging on a sugar source at 100 μT, which is at the higher end of levels that pollinators would encounter foraging in ground vegetation (Shepherd et al., 2018). These effects on bee cognition and behaviour are in response to experimental EMF fields that exceed predicted field-realistic exposure at ground level (5–15 μT) (Burda et al., 2009) where the bulk of bee activity occurs. Nonetheless, this study provides a basis for future research to conduct semi-field experiments that corroborate and extend this line of enquiry by adding more biological realism.

Hitherto, laboratory investigations into the physiological or developmental responses of invertebrates focussed on short-term or acute exposure to experimental sources of EMR. No studies have examined effects on invertebrates of long-term or chronic exposure to sources of anthropogenic EMR (Malkemper et al., 2018). This is potentially a more realistic type of exposure and may reveal sub-lethal effects as observed in pesticide impacts on pollinators (reviewed in: Godfray et al., 2014; Godfray et al., 2015; IPBES, 2016). Experiments that examine the potential multifactorial interplay (Vanbergen et al., 2013) between EMR exposure and other environmental stressors (e.g. pathogens, environmental pollutants or chemicals) (IPBES, 2016) affecting pollinator health and reproduction would also be valuable.

3.2. Field and semi-field experiments and surveys

Overall, the EKLIPSE assessment found that there is a dearth of scientifically robust evidence of EMR impacts on invertebrates from field or semi-field situations. Most available field studies conducted to date are dominated by deeply flawed investigations (scored 0 or 1) that are zero or under-replicated or anecdotal and consequently provide little meaningful data on which to judge the risk of exposure to anthropogenic EMR (Malkemper et al., 2018). There were a very restricted number of more robust field studies albeit with some remaining problems associated with scale and scope (score = 2). A single honey bee hive experiment provided some indication that very close proximity to AREMR (900 MHz) can affect honey bee colony acoustic behaviour (worker bee piping) associated with swarming or disturbance (Favre, 2011). Whilst this experiment (score = 2) had some design strengths (included negative and sham controls) it was, given the natural variability of honey bee colonies, under-replicated with only five colonies tested (although there were 12 runs) (Favre, 2011). Another more recent honey bee experiment (random frames of bee larvae from eight colonies split and assigned to AREMR (925–960 MHz) or control treatments with two runs) showed that exposure increased mortality during pupation and reduced hatching rate of the new queens, however, this did not translate into reduced subsequent mating success or colony size (Odemer and Odemer, 2019). Importantly, the AREMR exposure in these studies was not field-realistic because the emission source was from mobile phones placed inside the hives (Favre, 2011; Odemer and Odemer, 2019). This was an acute and highly artificial level of exposure, acknowledged as a worst case scenario by Odemer and Odemer (2019), and a feature shared with studies evaluated as being of the poorest scientific quality (score = 0 or 1) (Malkemper et al., 2018).

In field realistic settings, a well-executed and robustly analysed survey (score = 2) of wild pollinator communities around 10 mobile phone antennas using high frequencies (800–2600 MHz) and distributed across two Aegean islands revealed complex effects on insect abundance (Lázaro et al., 2016). This analysis revealed a complex correlation between the variable anthropogenic electric field (range 0.01–0.67 $V \cdot m^{-1}$) and insect abundance, measured at distance intervals (50, 100, 200 and 400 m) from the antenna, but these were contingent on the insect taxon and sometimes varied with geographical (island) location. Greater exposure to EMR was related negatively (hoverflies; wasps), positively (underground nesting wild bees and bee flies) or uncorrelated (butterflies) to abundance and had no effect on species richness (wild bees, hoverflies) (Lázaro et al., 2016).

Another similar field study (Vijver et al., 2014) of four phylogenetically distant invertebrate taxa (Collembola, Heteroptera, Hymenopteran parasitoid and *Drosophila melanogaster*) found no effects of controlled (Faraday cages, blind recording) exposure to EMR from a mobile antenna on reproductive capacity subsequently measured in the laboratory. Caveats to this experiment (score = 2) are that the field exposure was very brief (48 h) and whilst well replicated at the observation level (number of caged individuals) it was un-replicated at the treatment level (single exposure site) limiting its capacity for generalisation.

4. Overall quality of studies of AREMR effects on pollinators and other invertebrates

Overall, of the primary research reviewed the highest quality studies (score = 3; 23% of the papers) reported on the fundamental nature of interactions between invertebrates and naturally occurring electromagnetic fields. Such studies were always laboratory based, well replicated and controlled (Malkemper et al., 2018). The next tier of studies (score = 2; 38%) mostly comprised laboratory studies focussed on anthropogenic EMR, such as frequencies or wavelengths produced by mobile phone masts. These were very mixed with respect to scientific quality: sometimes replication appeared at a reasonable and appropriate level, but often a lack or underreporting of the design, replication or methods meant that the study could not be evaluated properly (Malkemper et al., 2018). The few field studies in this tier of study (score = 2; 38%), reported negligible or contrasting effects on behaviour or abundance. The remaining field and laboratory studies (score = 0 or 1; 39%) were anecdotal or flawed from the perspective of scientific design, such as having very low or non-existent levels of replication, pseudoreplication, highly unrealistic treatments, or sometimes a combination of all flaws (Malkemper et al., 2018). Consequently, no meaningful information can be gleaned from such studies.

5. Key messages and evidence confidence ratings

- ALAN can modify nocturnal pollinator communities and foraging behaviour to change pollination and plant reproduction [Figs. 3 & 2: *established but incomplete*]. These nocturnal changes may transmit to and alter diurnal pollinator communities and pollination via species interaction networks [Fig. 3: *established but incomplete*]. ALAN will increase in prominence as a driver of change as global urbanisation proceeds [Fig. 3: *established but incomplete*].
- Naturally occurring EMR is detectable by invertebrate physiological mechanisms governing orientation or movement [Figs. 3 & 2: *established but incomplete*]. AREMR has the potential to effect such physiological mechanisms, but robust scientific evidence is currently equivocal or lacking [Figs. 3 & 2: *inconclusive*].
- The limited number of well-executed laboratory experiments show that EMR can affect behaviour or reproduction of the honey bee *Apis mellifera* and other model insect species (e.g. *Drosophila melanogaster*), but effects are variable, negligible or inconsistent between studies [Figs. 3 & 2: *unresolved*] and do not necessarily translate into AREMR impacts on pollinators (or other invertebrates) in ecosystems.
- Current evidence of impacts of AREMR on pollinators (or other invertebrates) from field- or semi-field studies is very limited with only a single scientifically robust ecological study of impacts on wild pollinators (Lázaro et al., 2016), which reported positive and negative effects depending on the pollinator group and geographical location [Figs. 3 & 2: *inconclusive*].

6. Future research recommendations

To evaluate properly the potential threat to pollinators and other invertebrates from exposure to anthropogenic EMR requires further research. In particular, new research is required to assess the hitherto unstudied effects on pollinators and other biodiversity of emerging AREMR technologies and infrastructure (e.g. 5G, 'Internet of Things') (Bandara and Carpenter, 2018; Bin Zikria et al., 2018; Russell, 2018).

Importantly the overall scientific quality of investigations must improve if we are to obtain a realistic picture of the level of risk (Makinistian et al., 2018). Future studies must be hypothesis driven, based on a sound theoretical framework that allows for testable predictions of the experimental or survey outcomes. Good study design is obviously essential, but seemingly overlooked in many instances. For example, replication at the level of the treatment (i.e. source of exposure) is necessary for effects to be generalised and appropriate controls are essential or, where not possible in some field situations, otherwise ensuring sufficient replication to allow statistical partitioning of effects of measured EMR levels from other correlates. Studies must also report sufficiently detailed technical information (e.g. EMR wavelength, frequency and duration of exposure), instruments or methods used in experiments, and any environmental covariates (e.g. weather) to ensure reproducibility, comparability and to facilitate future syntheses (Makinistian et al., 2018).

Studies must maximise the level of biological or ecological realism. As with research into pesticide impacts on pollinators (Godfray et al., 2014; Godfray et al., 2015; IPBES, 2016), exposure to anthropogenic EMR must be field-realistic mimicking accurately and not exceeding wavelengths and frequencies encountered by pollinators in the field. As seen with other driver combinations (Godfray et al., 2014; González-Varo et al., 2013; Vanbergen et al., 2013), assessments of chronic exposure and the potential for additive or synergistic effects arising from exposure to single or multiple sources of ALAN/AREMR or in combination with other stressors (e.g. pesticides, pathogens, nutritional deficits) need testing to evaluate the overall level of risk from anthropogenic EMR. To understand field-realistic exposure and effects also requires consideration of pollinator species traits, such as nesting habits, foraging or dispersal behaviour and sociality, that will govern the level of impact of different sources of anthropogenic EMR alongside other drivers (e.g. land-use) (Potts et al., 2016; Vanbergen et al., 2013). Measuring pollinator responses to EMR exposure at different levels of biological organisation (species, population, community) and resulting change in pollination services (plant reproduction or crop yield) over the longer-term and, ideally, pre- and post-exposure would be especially valuable. For such field-realistic studies to be conclusive, would require their implementation across geographical regions in different semi-natural or anthropogenic ecosystems.

Interdisciplinary collaborations bringing together engineers, physicists, ecotoxicologists and biologists to test hypotheses about biological impacts at field-realistic exposure are more likely to avoid the conceptual or technical pitfalls that confound studies (Makinistian et al., 2018) and provide insights into the potential effects of anthropogenic EMR on pollinators and other insects.

7. Conclusion

Anthropogenic EMR emissions are proliferating but the extent that it is a risk to pollinators and pollination is currently unclear. There is some recently published evidence that ALAN may alter pollinator communities and functions, although there is a need for further high quality studies whose results align before we can conclude that ALAN is a major driver of change in pollinators and pollination. Our current knowledge of the impact of AREMR on pollinators (and other invertebrates) is inconclusive or unresolved and hindered by the scarcity of high quality scientific studies. Most experiments and field studies suffered from poor scientific method, underreporting of scientific or technical details that obstruct their assessment, and use of highly unrealistic exposure to AREMR sources. The extent that anthropogenic EMR (ALAN or AREMR) represents a significant threat to insect pollinators and the benefits they provide to nature and humankind therefore remains to be clearly established.

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Electromagnetic Radiation (EMR) on invertebrates and other wildlife. Thanks to Lise Goudeseune (Belgian Biodiversity Platform) and Estelle Balian (http://fea-l.eu/contact) for their work in searching the scientific literature, coordinating and organising the expert group, stakeholder conferences and reporting.

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