EKLIPSE

Knowledge & Learning Mechanism
on Biodiversity & Ecosystem Services

The impacts of artificial Electromagnetic Radiation on wildlife (flora and fauna). Current knowledge overview: a background document to the web conference

A report of the EKLIPSE project

buglife

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The impacts of artificial Electromagnetic Radiation on wildlife (flora and fauna). Current knowledge overview: a background document to the web conference.

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1. Context and objectives

Organisers

EKLIPSE is an EU funded Coordination Action under H2020, aiming to develop a European Mechanism to answer requests from policy makers and other societal actors on biodiversity related issues.

EKLIPSE had a first "Call for request" in September 2016. The request submitted by Buglife on the impacts of anthropogenic electromagnetic radiation on invertebrates was selected to initiate a process of identifying key knowledge gaps and research needs, as well as to formulate recommendations. The scope of the request has been adjusted and it now extends to the impacts on invertebrates, vertebrates, and plants, and the range of EMR types has been reduced.

After a first scoping to compile a list of publications relevant to the topic, EKLIPSE has invited selected experts to join Experts Steering Group to analyse the publications and help prepare the organisation of a larger consultation through a web conference. The Experts Steering Group is multidisciplinary: it is composed of four biologists/ecologists specialised in different taxonomic groups, as well as two physicists having worked with electromagnetic field (see Appendix I - Members of the Experts Steering Group).

This document provides the results of the first scoping and analysis of available literature by the Experts Steering Group to provide a knowledge overview and identify knowledge gaps. It is a working document and it will lead to a more elaborated report integrating the results of the web conference

Objectives

This overview aims to identify which main taxonomic groups, which types of EMR, and associated effects have been addressed by the existing studies.

It will also assess the level of quality/reliability of the available studies on both technical and biological/ecological aspects.

Based on this overview, key knowledge gaps and assessments of the quality of the studies have been identified and have served as the basis of discussions for the larger consultation (web conference) that was organised by EKLIPSE at the beginning of 2018. This background document should be considered as a technical working report and does not aim to be exhaustive but rather to provide a first step in the analysis of the currently available knowledge and future research needs.

2. Knowledge overview methodology

2.1 Scoping of the literature

The literature used was restricted to peer-reviewed articles. The search for publications was made on the ISI Web of Knowledge platform and it was completed by searches on Google Scholar, using the following combinations of keywords:

- EMR; EMF; electrosmog; electromagnetic field; electromagnetic radiation; electromagnetic

AND

- wildlife; invertebrate(s); vertebrate(s); plant(s); animal(s); insect(s); arthropod(s); bee(s); drosophila; mammal(s); fish; amphibian(s); bird(s); tree(s); flower(s); biodiversity.

The publications cited in the identified papers were also examined to complement the list. A further search was done with the names of recurring experts. Only recent papers (from 2000 onwards) were considered.

The focus was made on wildlife (plants, invertebrates, vertebrates), although a few studies on domestic animals have been included.

The range of EMR types has also been restricted to artificial anthropogenic radiations. For example, it does not include research on the effects of light, the Earth's magnetic field, MRI-strength magnetic field, etc.) Studies that were considered out of this scope were discarded and not used in the analysis.

A Call for Knowledge was launched on the EKLIPSE KNOCK Forum (interactive discussion platform) and additional publications, suggested by the contributors, were added to the list. Finally, the experts from the Experts Steering Group provided a few more relevant sources.

In total, 147 scientific papers or reviews were identified, and 97 of them were used in the analyses (see list of References).

This final list of publications does not aim to be comprehensive, but to compile a representative set of papers and studies to allow an overview of the current knowledge and gaps.

2.2 Structuring of the literature and analyses

The Experts Steering Group structured the analyses in two different axes. On one hand, the biologists/ecologists divided the work amongst them according to three major taxonomic groups: 1/ invertebrates, 2/ vertebrates, 3/ plants. On the other hand, the physicists/engineers have created 15 categories of anthropogenic radiation types based on frequency and exposure identified by codes (see Table 1).

Table 1 Categorisation and identification of radiation types

Category	Identification
Non-specific magnetic fields	Static magnetic field
	Extremely low frequencies (< 1 kHz)
Non-specific electric fields	Static electric field
	Extremely low frequencies (< 1 kHz)
Non-specific radiofrequencies	Between 1 kHz and 6 GHz
Non-specific microwaves	Between 6 GHz and 300 GHz
Non-specific infrared	Between 300 GHz and 430 Thz
Application specific exposure	Power lines magnetic field (50 or 60 Hz)
	Power lines electric field (50 or 60 Hz)
	Analog broadcasting-like signals (TV, radio)
	Digital broadcasting-like signals (TV, radio)
	2G base station-like signals (GSM)
	3G base station-like signals (UMTS)
	4G base station-like signals
	Radar-like signals

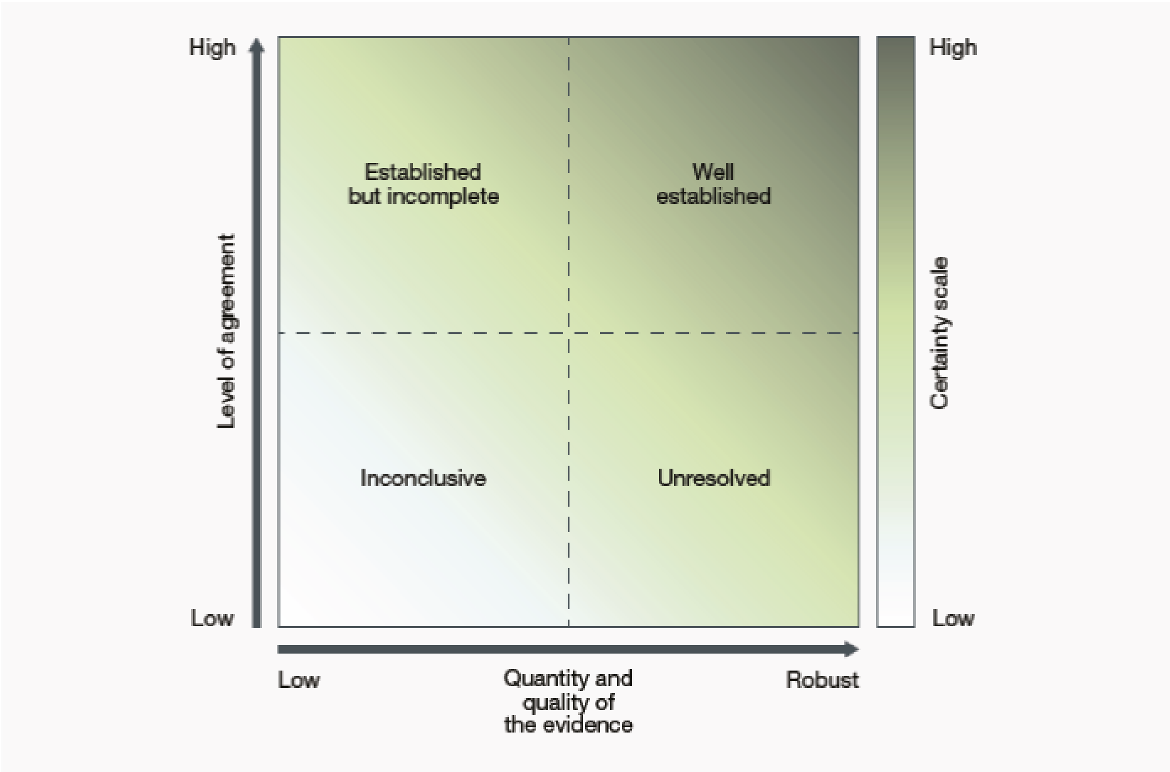
Then, an analytical grid was produced with the publications identified per taxonomic group and radiation type. Different comment sections were added to assess the quality of the studies (technological aspects and biological aspects), the conditions of the studies, the results, the knowledge gaps, etc.

The following rating system was used:

1. bad quality
2. minimum quality, with some elements that can be used
3. normal quality, some gaps
4. excellent

2.3 Assessment of the confidence levels of the studies

In this background document, we make an initial attempt to distil the assessment of the published scientific literature into a series of 'key messages', which are succinct statements aimed at conveying important information to the web conference participants and, ultimately, to decision-makers. The scientific evidence assessed included empirical data, theory, and models.



The summary terms to describe the evidence are:

- **Well established:** comprehensive meta-analysis[19] 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 that exist imprecisely address the question.
- **Unresolved:** multiple independent studies exist but conclusions do not agree.
- **Inconclusive:** limited evidence, recognising major knowledge gaps

Confidence increases towards the top-right corner as suggested by the increasing strength of shading. Source: modified from Moss and Schneider (2000).

Figure 1 Four-box model for the qualitative communication of confidence.

For scientists and decision-makers to understand the level of the potential problem it is crucial that the degree of confidence in each key message is evaluated and communicated in ways that are effective but simple enough for a range of audiences to understand. In our assessment of the published evidence about the effects of EMR on wildlife we employ a qualitative 'four-box model' to communicate the level of certainty in knowledge, this allows us to show how each key message is based on the assessment of the quantity, quality and level of expert agreement in the evidence (see Figure 1). This model follows and is adopted from the Intergovernmental Platform for Biodiversity & Ecosystem Services (IPBES, 2016), which in turn adapted the model from Moss and Schneider (2000), which uses this approach to convey messages of its assessments to intergovernmental policymaking.

3. Key results: current state of knowledge

3.1 Quality of the studies in terms of technical aspects

a. Invertebrates

This document aims to frame the current knowledge about the impacts of EMR on wildlife as based on an assessment of the scientific literature. It is expected that debate and challenge during the web conference will either confirm our assessment of the evidence, the level of certainty, and the knowledge gaps or produce additional evidence that may stimulate a reassessment of the evidence and the resulting key messages to decision makers.

The quality of published studies investigating the impacts of EMR on invertebrates is very mixed. On the one hand, results from studies carried out in the laboratory are often not transferable to real life situations due to an oversimplification of effects and the limited exposure (both in time and space) to EMR of the subjects.

On the other hand, field studies suffer from a multitude of unmeasured potential effects that are indirectly related to EMR levels and can often not be disentangled, thereby confounding analysis. Field studies also often suffer from (very) low replication which makes drawing firm conclusions difficult.

Certain studies of very poor scientific quality (e.g. no or very low replication) employed highly artificial EMR treatments, such as placing a mobile phone either inside or immediately adjacent to honey bee hives. This represented a highly field-unrealistic exposure to a source of EMR and, even putting issues of replication aside, would mean no rigorous conclusions can be reached.

b. Vertebrates

Studies on the effects of time-varying magnetic fields on vertebrates are highly variable in terms of the exposure and the read-outs used to investigate possible effects. The magnetic fields range from extremely low frequency power line fields “applied” in the field to highly controlled gigahertz fields in the laboratory. Study qualities in terms of technical aspects are equally inhomogeneous. Not even half of the studies assessed were given the highest technical ranking (see Appendix II - Tables with number of assessed studies). The often poor design and missing control experiments impair assessment of the validity of the results and are likely to be the main reason for a low number of cross-laboratory replicated results. Unfortunately, the great variability in the qualities of primary research papers is not reflected in many reviews on the topic. Often, these reviews do not report selection criteria for the inclusion of studies. In addition, reviews suffer from the problem of comparing studies with highly variable descriptions of technical details on exposure parameters which hampers condensing similarities among the findings. In our assessment the studies with the lowest ratings in terms of technical aspects were:

1. Not blinding the experimenters
2. Not including appropriate controls
3. Inadequately characterized EMR exposure

We recommend that both laboratory studies and field studies which are equally important should apply to standard methodological criteria which are listed below in 3.1.4. As biologists are usually not experts on RF-physics, collaborations with physicists and engineers are crucial to achieve reliable exposure conditions. Studies on the effects of exposure in the fields should be accompanied by lab studies which simulate the exposure under normal environmental conditions which some studies did quite well. The currently biggest issue is the time of exposure, as long-term studies are mostly missing. The development of devices to expose wild animals for a long time to controlled RF in the field should be impelled (e.g. coil-collars or large coil systems around enclosures).

c. Plants

Plants are outstanding models to study the impact of EMR on biological systems. Indeed, they are immobile and therefore can't escape from an environmental constraint and keep a constant orientation in the EMR. Their high surface to volume ratio place a high proportion of cells at the direct interface of the environment and are deprived of awareness, thus eliminating the interference with stressful conditions that could be encountered with animal experiments.

The technical aspect of the studies performed on plants ranked from very poor to excellent. The control of the exposure conditions is one of the most difficult to overcome. Concerning the laboratory studies, one could avoid the use of communication devices such as cell phones to expose sample since their automatisms make difficult to control the emitted EMR and the samples are placed near the device in a region where the EMR is not well established (near field) and difficult to control and measure.

The studies conducted in the field are comparatively less abundant and raise two difficulties: i) the first is to efficiently measure the level of EMR in an open environment, where it may vary in nature and amplitude along the day; ii) the second is to avoid / limit or understand the interference with other environmental traits (wind, temperature, pathogens...) that may compromise or make difficult the interpretation of biological responses. The parameters that are used to report the EMR effect on plant are diverse and of unequal value. A high proportion of laboratory experiments concentrate on biochemical or molecular changes that occur shortly after sample exposure. They are using standardized protocols and are generally well conducted, but a greater attention should be paid to control samples. Indeed, most of biological traits vary along the day and changes may reflect natural events rather than responses to EMR if the proper control samples are not performed. Modifications of plant growth after exposure should be conducted with great care since they reveal delayed effects of the exposure and the experiments last for several days during which it can be difficult to avoid interference with other factors that could lead to misinterpretations.

Recommendations for future lab studies could include the use of dedicated devices (TEM-Cell and G-TEM) that offer several advantages, particularly the ability to obtain high EMR amplitude with relatively low injected power, and a very good control of the electromagnetic field characteristics. These devices however only allow the generation of polarized EMR, a situation that is rarely encountered in the true environment, especially in an urban environment, were the signals are reflected and diffracted. The mode stirred reverberation chamber (MSRC), is designed to mimic this situation and has proven to be a very valuable tool as exposure device. However, the cost and complexity has limited the use of this facility.

The field experiments are extremely interesting since plants are still witnesses of their environment and should report long term exposure effects in natural conditions. They are generally using an approach based on the observation of symptoms, linking appearance defects with exposure to electromagnetic fields. Since this approach could be a good starting point, the formal link between the symptoms and the exposure should be established with complementary laboratory studies.

Another key recommendation would be to ensure collaboration with physicists to avoid errors in the set-up of the experimental procedures and/or of the exposure level measurement.

d. General and cross-cutting observations

The studies with the highest rankings set the benchmark for the minimal requirements a future study should meet to be suitable for publication in peer-reviewed journals:

1. Data collection and/or analysis must be conducted in a blinded fashion to minimize observer bias
2. Proper controls for side effects accompanying magnetic exposure, such as vibrations, heat and electric fields need to be accounted for, e.g. by using double-wrapped coils.
3. Whenever magnetic fields are applied it needs to be made sure that all experimental groups are exposed to the same background field by shielding (Faraday cage). In any case the background field needs to be reported through continuous broadband measurements.
4. The magnetic fields used need to be accurately measured and the measurement devices and results reported in detail: Sensitivity of the devices, frequency (-range), intensity, polarization, duration, direction

Collaboration with physicists to better prepare and implement the technical protocols is a major aspect for ensuring technical quality of the studies.

3.2 Quality of the studies in terms of biological or ecological aspects

a. Invertebrates

Physiological and histological studies were usually well replicated and the scientific approach in terms of replication and analysis of the results was satisfactory.

There is a real lack of ecological studies looking at the effect of EMR on species assemblages. One study points out some guilds that seem to be less affected by EMR possibly due to different life history traits that minimise exposure levels at critical life stages. There are no published studies of effects of EMR on species interactions.

From a scientific and technical perspective, the best primary studies (i.e. those receiving a score = 3) tended to be those reporting on the fundamental biology of interactions between insects and naturally occurring electromagnetic fields. Such studies were always laboratory based, well replicated and controlled. Overall the next tier of primary studies (graded as score 2) were more focussed on anthropogenic sources of EMR, such as that produced by mobile phone masts, but were mostly laboratory based. This set of studies was very mixed with respect to scientific quality, sometimes replication appeared at a reasonable and appropriate level. However, a lack or underreporting of the design, replication levels or methods sometimes meant that the study could not be evaluated properly. Of the few field studies, there were either negligible, contrasting effects on behaviour or abundance.

The remaining field and laboratory studies (graded 0 or 1) 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. Consequently, no statistical analysis can be done and no meaningful information can be gleaned from such studies.

b. Vertebrates

Readouts for effects of EMR on vertebrates span the whole spectrum from hormone levels and other physiological parameters to behaviour. Many of these readouts might have ecological implications (relevant for species survival and thus of interest for conservation efforts) but real ecological studies are extremely rare. The lack of ecological studies is most probably based on the number of environmental variables that effect ecological communities which makes it hard to identify the influence of EMR in a controlled manner.

The studies focussing on single species often in a laboratory setting suffer from an additional and very general problem: They are not based on hypotheses of how EMR could influence biological structures and thus are not following hypothetico-deductive methodology. Therefore, the effects found are not explainable and no dose-response relationships are revealed. The exposure levels vary dramatically between studies and results are rarely replicated across laboratories.

However, there are two exceptions:

1. Heat effects: It is undisputed that strong EMR fields increase the temperature in tissue and many EMR effects found in (especially older) studies can explained by hyperthermia. However, the EMR intensities needed to induce the heating are not experienced by wildlife (so far).
2. The magnetic sense of birds: Two main hypotheses for the transduction mechanism are supported by manifold evidence and the influence of EMR can be specifically predicted and tested.

Of the 20 primary research studies rated in this assessment one quarter was of very low quality in terms of the biological aspects (see Appendix II - Tables with number of assessed studies). Of the rest, one half (7) was of mediocre quality while 8 studies where excellent, with clear hypothesis-based predictions that were specifically tested. 62.5% of these excellent studies were from the field of animal magnetoreception.

c. Plants

Angiosperms are by far the main taxonomic group to be studied (only a few used mosses).

The principal point is to achieve a formal link between the exposure and the biological responses, thus the main issue is to avoid the intrusion of environmental factors that may interfere with the conclusions. This point is especially critical for plants since their immobility make them very sensitive to even minute changes (light, mineral nutrition, wind, etc.). Basically, and apart from the lab/field point of view, studies can be divided in two:

1. those exposing seeds or seedlings and looking at events (biochemical and growth modifications) that follows the exposure. These had the advantage of using «naive» samples (i.e. with no or limited life history before the exposure) that self-feed on their reserves. They however present the disadvantage of incomplete metabolism and/or limited organ development that may minor interaction with EMR.
2. older or adult plants that present the advantage of fully functional metabolism (in particular the photosynthetic apparatus) and well developed vegetative organs to ensure efficient EMR signal pick-up. These models require however careful handling and constant environmental conditions over the exposure, this can only be achieved effectively in the laboratory.

While the experiments could be easily repeated in laboratory, field experiments could suffer from single observations that it may be difficult or impossible to observe a satisfying equivalent. These approaches should avoid such situation and concentrate on samples that are present similar exposure conditions and symptoms.

d. General and cross-cutting observations

Double-blind experimental procedures are ideal for exposures protocols. Anyway, special attention should be paid to set-up adequate controls and to properly evaluate the level of exposure. Also, the use of communication devices as EMR source should be avoided.

Of the reviews, the majority are not systematic or objective but appear to be unbalanced and asserting a particular world view (i.e. that it is a problem for biodiversity) without strong supporting evidence.

Cryptochromes are particularly interesting as they occur across all groups.

3.3 Key findings: studied organisms and observed effects

a. Invertebrates

Organisms studied for impacts of EMR are the western honey bee (*Apis mellifera*), *Drosophila* flies, specific beetle species, ants and in one/few cases wild pollinators (Diptera, Hymenoptera, Lepidoptera, Coleoptera).

Few, often high quality, published experiments on the fundamental biological responses of insects to naturally occurring electromagnetic fields (or experimentally imposed fields closely mimicking nature or their lack) demonstrate how insects detect and orientate with electrical or magnetic fields and the effects (or lack of) on behaviour, physiological function, reproduction. While providing some mechanistic basis for hypothesis testing, such studies do not provide evidence on effects of anthropogenic sources of EMR on invertebrate biodiversity.

The majority of laboratory studies are focussed on physiological or developmental responses to short-term or acute exposure to experimental sources of EMR. There are no studies that examine effects on invertebrates of long-term or chronic exposure to sources of anthropogenic EMR.

Effects on insects tend to be often complex, typically variable in direction or effect size, and only sometimes adverse. Of the few scientifically rigorous laboratory experiments on model species (i.e. *Drosophila*) there is some evidence of exposure leading to cell damage or effects on individual development, locomotion, or reproduction.

There is a dearth of evidence from scientifically robust field studies, those that are available range from deeply flawed investigations that provide no meaningful evidence to a very restricted number of relatively robust studies albeit of limited scope. Of the latter, there have been studies that have shown some evidence that close proximity to EMR (from mobile phones) can affect honey bee colony behaviour, that exposure to mobile phone antennas can elicit idiosyncratic effects on wild pollinator abundance according to taxon, and no effects on reproductive capacity.

b. Vertebrates

In vertebrates, there is not much agreement on the effect of EMR on ecologically relevant parameters. Studies reporting effects are approximately as frequent as those reporting no effects (50-50%).

Few studies exist on direct ecological effects such as species abundance near RF-towers or in cities where background EMR levels are elevated. The descriptive nature of the studies, however, makes it impossible to detangle real EMR effects from other confounders such as light-pollution. There is some evidence that animals might avoid strong radiation sources such as radar and mobile phone towers but the few studies do not allow drawing definite conclusions about ecological implications.

Studies on physiological effects lack theoretical foundation which makes them appear as shots in the dark, a scientific practice which is prone to type I errors (finding effects that are not real). The reported findings range from effects on redox reactions and hormone levels to altered nociception and growth rates and malformations during (embryonic) development. Of these, a reducing effect of repeated exposure to a zero magnetic field on nociception seems to be the most established finding, even though completely independent replications are still needed. While many of the observed effects might be real, only strict hypothesis driven research based on a priori established theoretical models will eventually help to identify the RF real effects and the mechanisms underlying them. Dose-effect relationships are missing but as a rule, longer exposures where more often reported to have an effect. Birds comprise the most studied group of vertebrates followed by small rodents such as mice and rabbits. In sum, the findings of RF influence on physiological parameters in vertebrates can be described as contradictory and inconclusive.

By the far the most advanced theoretical foundation concerns the effects of RF fields on magnetic orientation migratory birds. Currently, there is strong evidence that the sensor is based on radical pair intermediates (perhaps in a protein called Cryptochrome) which are naturally sensitive to magnetic fields in the radiofrequency range. It is established that the magnetic compass of migratory birds can be disrupted by the weak RF background in larger cities (nT-intensities) but it is currently unclear which exact frequencies are most effective. Furthermore, some studies have suggested that fields emanating from power lines also affect the magnetic sense of vertebrates but again it is unclear whether this is effect is specific to 50Hz-MF or to harmonics or even electric fields. More and more evidence is accumulating that mammals (e.g. bats and mice) have a magnetic sense which might be based on radical-pairs and as such will likewise be affected by RF. It remains to be tested whether disruption of a magnetic compass has real ecological consequences as animals make use of a variety of mechanisms for orientation.

c. Plants

Mainly Angiosperms. Significant changes have been demonstrated at cellular and molecular levels. Changes in oxidative metabolism are quite often reported~: increase in peroxidase activity, membrane state. Exposure to low level of 900 MHz (10 min, 5 V/m) caused a rapid increase in stress-related transcript accumulation in tomato. The role of calcium has been characterized in this model by using chelators and by measuring the calmodulin gene expression. Calcium and a normal behaviour of the plant hormone abscisic acid are required to achieve the stress-related transcripts accumulation that occurred in a systemic way in plants; the energy metabolism is also transiently affected (about 30%). The genotoxicity of EMR is also questioned in some article. However additional data are still needed here since these methods could easily bring false positives. Terpene emission was reported to be enhanced by EMR and could also be considered as a marker of stress perception.

The metabolic and/or gene expression changes were not always related to changes in plant growth and development. It is however an excellent way to realize the integration of the EMR perception and responses in the development of the organism. However, several articles report impact on plants growth and development after exposure to EMR. The growth was reported to be reduced, either soon after the exposure or after a delay of several days, when new organs are created.

3.4 Knowledge gaps and research needs

a. Invertebrates

There is a dire need for more ecological studies, which measure the effects of EMR on wild communities. Studies which measure the community responses (abundance, diversity and ecosystem functioning) long-term and ideally pre- and post-exposure would be especially valuable. In order for such studies to be conclusive they would have to be carried out over a wide geographical extent and in different natural and anthropogenic systems. In addition, interdisciplinary collaborations that test hypotheses drawing on what is known about insect physiology to test probable biological and ecological impacts (and avoid speculative ad-hoc approach) at field-realistic exposure could give important insights.

We also need studies that assess chronic effects, as these are more likely to be occurring, as well as experiments that examine the potential interplay between EMR exposure and a) foraging ecology and b) other stressors (e.g. pathogens, environmental pollutants/chemicals) affecting nutritional ecology.

b. Vertebrates

In the field of animal magnetic navigation, knowledge about the definite receptor mechanism mediating the perception of the Earth's magnetic field will greatly facilitate the assessment of the effect of man-made magnetic fields on the ecology of wild migrants. Along the same lines, if it turns out that the receptors are also present in non-migratory species, but that they might fulfil a different function (e.g. in circadian rhythms in case of Cryptochromes) it will need to be assessed whether it still retained remnant magnetosensitivity that might be responsible for physiological effects of man-made magnetic field on organisms.

Studies on the effects on long-term exposure (e.g. throughout development) are needed.

Furthermore, real ecological studies are missing. Do electromagnetic fields have an effect on species populations? In order to reduce confounding effects of other factors, such studies should be performed on small vertebrates with fast reproduction rates under highly controlled conditions in outdoor enclosures as well as on whole communities using gigantic coils or antenna systems or perform meta-analyses on established data-sets by taking RF-data into account. To enable such studies in future, the establishment of fixed RF-measurement stations (e.g. at already established geomagnetic observatories) would be beneficial.

c. Plants

There is the need to improve the quality of the exposure system: to stop using telecom devices and prefer TEM/G-TEM cells and other well-defined devices.

Also, to use reliable markers (enzymatic and/or gene expression) which are both inexpensive and allow to report changes in the behaviour of plants. These markers also bring valuable information of molecular events that occur shortly after exposure. They also allow a better link with the exposure than growth studies that may integrate environmental signals other than EMR, leading to misinterpretations.

Ideally, these biochemical/molecular studies should be completed by growth studies to assess changes at the scale of the whole plant. Field experiments should this way relate symptoms observed to biological/molecular changes.

d. General and cross-cutting observations

- EM set up and quality: some technical standards/parameters that have to be included in future studies (to ensure replication)
- Studies on chronic/long-term exposure (with realistic exposure settings mimicking those in the field)
- Studies should be hypothesis driven, i.e. that should be based on a theoretical framework that allows making predictions of the outcome of the experiment
- Thermal- and non-thermal effects need to be clearly distinguished (exposures should not exceed relevant levels that could be encountered by wildlife in the field)
- Exposure systems that can be used in the field should be further developed

4. Conclusions

4.1 Invertebrates

EMR is an environmental cue detectable by invertebrate physiological mechanisms governing orientation or movement [*established but incomplete*].

EMR from anthropogenic sources (e.g. mobile phones) represent a potential risk to such physiological mechanisms [*established but incomplete*], but current evidence is limited, both by the number and quality of studies [*inconclusive*].

There is some evidence that anthropogenic EMR in laboratory experiments can affect behaviour or reproduction of model insect species such as the fruit fly Drosophila melanogaster), although effects are often negligible or inconsistent between studies [*unresolved*].

Currently evidence for effects of EMR on the diversity or abundance of invertebrates is very limited. Few ecological studies exist, but when they do, the reported EMR effects are negligible, contrasting, or cannot be separated from other environmental factors (e.g. land-use) [*inconclusive*].

The majority of experimental and field studies suffered from poor scientific method (e.g. zero or under-replicated, lack of covariate measurements), field-unrealistic exposures to EMR sources, or underreporting of scientific or technical details making evaluation difficult.

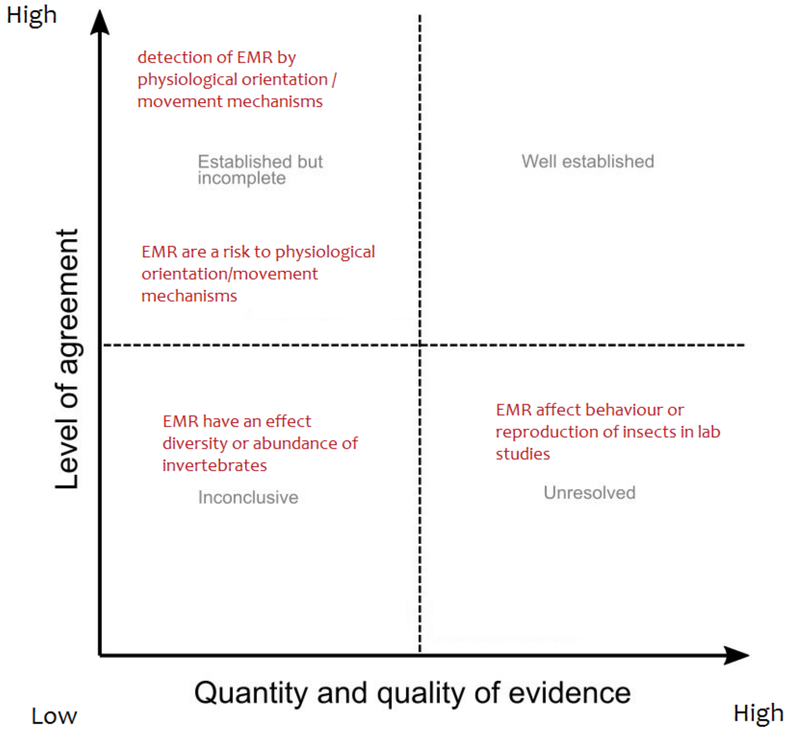


Figure 2 Level of confidence of the statements for the invertebrates

4.2 Vertebrates

Magnetic orientation of birds can be disrupted by weak magnetic fields in the radiofrequency range [*established but incomplete*], the same might be true for the magnetic sense of other vertebrates including mammals [*inconclusive*]. The ecological consequences of this compass disruption are completely unknown [*inconclusive*].

Some evidence points towards an influence of EMR not based on hyperthermia on the embryonic development of birds [*inconclusive*].

EMR seem to have an influence on vertebrate physiology, nociception in particular, but the mechanisms by which physiological effects are mediated are unclear [*unresolved*].

Whether EMR influence species abundance and distribution and thus biodiversity is completely unclear to date [*inconclusive*].

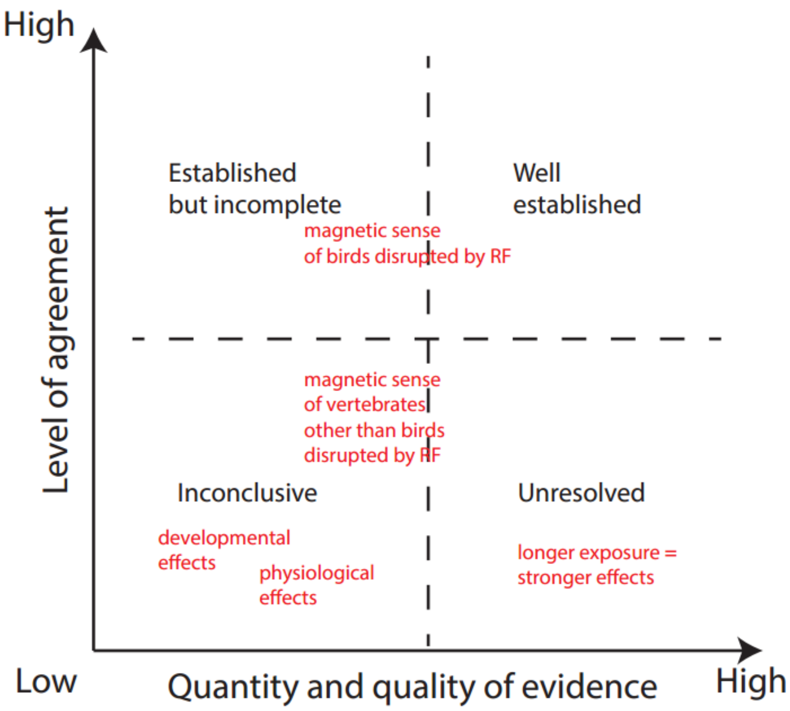


Figure 3 Level of confidence of the statements for the vertebrates

4.3 Plants

Several experiments conducted in laboratory tend to show that plant metabolism is affected by exposure to EMR [*established but incomplete*], particularly the ROS metabolism. However, the diversity of the exposure procedures makes it difficult to construct a clear scheme of what is happening in terms of metabolic changes [*inconclusive/unsolved*] after exposure to EMR. The rationalization of this aspect [*unsolved*] would enable the establishment of consensus by facilitating replications and enrichment of results by different research groups.

The impact of these changes on plant development is generally gathered as a growth reduction [*inconclusive*] but an unequivocal link of these changes with the exposure remains difficult to establish since plant growth integrates many environmental traits that may interfere with the conclusions. This is particularly true for field experiments [*inconclusive*] where the knowledge acquired after laboratory research would help to decipher what kind of symptoms could be truly attributed to EMR effects. Thus, it remains difficult to clearly state the exact impacts of EMR on plants in the real environment with a good level of confidence.

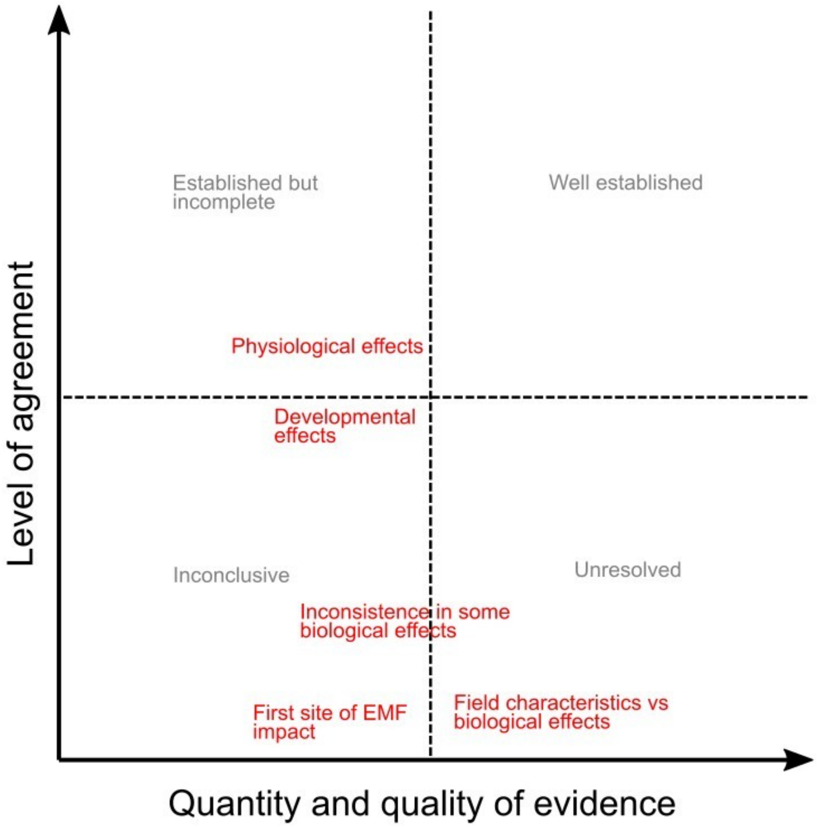


Figure 4 Level of confidence of the statements for the plants

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Appendix I: Members of the Experts Steering Group

Matt Shardlow (requester)

Buglife is the only organisation in Europe devoted to the conservation of all invertebrates, and we are actively working to save Britain's rarest little animals, everything from bees to beetles, worms to woodlice and jumping spiders to jellyfish. There are more than 40,000 invertebrate species in the UK, and many of these are under threat as never before. Invertebrates are vitally important to a healthy planet – humans and other life forms could not survive without them. The food we eat, the fish we catch, the birds we see, the flowers we smell and the hum of life we hear, simply would not exist without bugs. Invertebrates underpin life on earth and without them the world's ecosystems would collapse.

Prof Mario Babilon (expert)

Prof Babilon got his final degree in physics ("Diplom Physiker") in July, 2001 from the Technical University of Darmstadt. Thereafter he graduated in Nuclear Physics. During that time, he spent one year at Wright Nuclear Structure Lab at YALE University in the United States as a visiting assistant in research. He received his PhD in December 2004 and spent about one more year as a post-doc in Darmstadt, before switching to industry. He started a career in the corporate research department of BOSCH. Meanwhile he was giving lectures at the Cooperative State University in Stuttgart. He completely switched to the University in 2011 and since then he is a Professor in Computer Science.

Dr Erich Pascal Malkemper (expert)

Dr Malkemper is a biologist who received his PhD at the University of Duisburg-Essen in Germany. His thesis "The sensory biology of the red fox – hearing, vision, magnetoreception" was awarded the Fritz-Frank-Award of the German Society for Mammalian Biology in 2015. His research focusses on sensory systems, which he studies with behavioural experiments, histology and physiology, to understand ecological adaptations of a given species. He is currently based at the Research Institute of Molecular Pathology (IMP) in Vienna, Austria, where he conducts research on magnetoreception in homing pigeons.

Dr Benoît Stockbroeckx (expert)

Dr Stockbroeckx received the degree of Electrical Engineer from the Université Catholique de Louvain (UCL), Louvain-la-Neuve, Belgium, in 1993. He received his PhD degree in Applied Sciences in 1998 with a thesis on Space waves and surface waves in the Vivaldi antenna. He is involved in EMF exposure assessments since 1998. He is now the head of laboratory division at ANPI in charge of alarm systems, active fire prevention, theft prevention, CE marking (EMC, LVD, CPR), electromagnetic compatibility. He is also expert at the Belgian Health Council for non-ionising radiations.

Dr Thomas Tscheulin (expert)

Dr Tscheulin, holding a PhD in Population Ecology from Imperial College London, is currently an Assistant Professor at the University of the Aegean, Greece. He has a strong track record of collaborative research, both within and between host institutions in three different European countries. His main research interest is to relate assessments of the abundance, diversity, functional structure and trophic interactions of invertebrates, to the impacts of ecosystem disturbances such as agricultural practices, alien species invasion, climate change, wildfires, habitat loss and degradation. He is an associate editor for Animal Conservation and has so far published 36 scientific papers.

Dr Adam J. Vanbergen (expert)

Dr Adam Vanbergen is an invertebrate ecologist who received his PhD on 'Landscape to host-plant scales: bottom-up heterogeneity affects invertebrate diversity & interactions' from Cardiff University. He has been working for the Centre for Ecology & Hydrology since 1998. His research focusses on species interactions, community structure, and the relationship between biodiversity and ecosystem functions and services. He is particularly interested in understanding how anthropogenic disturbance across spatial scales governs diversity and interactions, above and belowground and at trophic levels directly (herbivores, pollinators) and indirectly (predators, parasites) connected to plants.

Prof Alain Vian (expert)

Prof Vian obtained his PhD in plant physiology at the University Blaise Pascal (1995) under the supervision of Dr Marie-Odile Desbiez, working on plant responses to wounding. He then performed a 2-years postdoctoral period in the laboratory of Prof. Eric Davies (North Carolina State University), working on the rapid molecular events following plant flaming. He obtained an assistant professor position at the university Blaise Pascal (Clermont-Ferrand) and rapidly specialized in plant responses to high frequency electromagnetic field, in collaboration with physicists (Profs Françoise Paladian and Pierre Bonnet). In 2008, he obtained a prize from the French Academy of Sciences for this work. He became full professor in 2009 at the University of Angers and since 2012 has worked in the Institut de Recherche en Horticulture et Semences (UMR 1345), studying the effect of environmental factors (mainly nitrogen nutrition) on the regulation of axillary bud outgrowth, a major event in the establishment of plant architecture. He is also continuing his work on the biological effects of high frequency electromagnetic field on plant development.

Appendix II: Tables with number of assessed studies

Quality of the studies in terms of biological or ecological aspects

Table 1: Invertebrates		
Total number of studies on Invertebrates *(not including reviews on all taxonomic groups)*	**39**	
Number of studies assessed	39	100%
Number of studies that were irrelevant/bad quality (0)	7	18%
Number of studies of minimum quality (1)	8	21%
Number of studies of normal/medium quality (2)	15	38%
Number of studies of excellent quality (3)	9	23%

Table 2: Vertebrates		
Total number of studies on Vertebrates *(not including reviews on all taxonomic groups)*	**20**	
Number of studies assessed	20	100%
Number of studies that were irrelevant/bad quality (0)	1	5%
Number of studies of minimum quality (1)	4	20%
Number of studies of normal/medium quality (2)	7	35%
Number of studies of excellent quality (3)	8	40%

Table 3: Plants		
Total number of studies on Plants *(not including reviews on all taxonomic groups)*	**23**	
Number of studies assessed	20	87%
Number of studies that were irrelevant/bad quality (0)	1	4%
Number of studies of minimum quality (1)	2	9%
Number of studies of normal/medium quality (2)	4	17%
Number of studies of excellent quality (3)	13	57%

Quality of the studies in terms of technical aspects

Table 4: Invertebrates		
Total number of studies on Invertebrates *(not including reviews on all taxonomic groups)*	**39**	
Number of studies assessed	26	67%
Number of studies that were irrelevant/bad quality (0)	7	18%
Number of studies of minimum quality (1)	2	5%
Number of studies of normal/medium quality (2)	5	13%
Number of studies of excellent quality (3)	12	31%

Table 5: Vertebrates		
Total number of studies on Vertebrates *(not including reviews on all taxonomic groups)*	**20**	
Number of studies assessed	20	100%
Number of studies that were irrelevant/bad quality (0)	2	10%
Number of studies of minimum quality (1)	7	35%
Number of studies of normal/medium quality (2)	4	20%
Number of studies of excellent quality (3)	7	35%

Table 6: Plants		
Total number of studies on Plants *(not including reviews on all taxonomic groups)*	**23**	
Number of studies assessed	16	70%
Number of studies that were irrelevant/bad quality (0)	2	9%
Number of studies of minimum quality (1)	3	13%
Number of studies of normal/medium quality (2)	1	4%
Number of studies of excellent quality (3)	10	43%

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