Effects of Non-ionizing Electromagnetic Pollution on Invertebrates, Including Pollinators such as Honey Bees: What We Know, What We Don't Know, and What We Need to Know

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Abstract
Invertebrates, including pollinators such as honey bees, can be adversely affected by non-ionizing electromagnetic radiation (EMR). Sources contributing to common environmental EMR exposures include antennae (cell phone, broadcast, and radar), communications satellites, and power lines. Adverse biochemical changes and disorientation have been reported for honey bees and other invertebrates. Field studies have reported changes in abundance and composition of "key pollinator groups" (wild bees, hoverflies, bee flies, beetles, and wasps) that have been attributed to emissions from telecommunications towers. We take a close look at the biological effects on invertebrates of EMR reported in the scientific literature and a general look at evidence from studies on plants, birds, humans, and other animals (domestic, laboratory, wild). We discuss possible implications of excessive electromagnetic pollution on ecosystems and identify knowledge gaps and what we need to know before more electromagnetic pollution is added to the environment, especially in the form of 5G.

Introduction
Invertebrates (animals without backbones) are major components of most ecosystems. Insects are key to the integrity of many ecosystems in many roles including as pollinators. Honey bees play a role in pollination of domestic as well as wild plants and are often used as bio-indicator species and as a "model" to examine environmental problems. The global decline of pollinators is of grave concern and efforts are being made to identify the reasons (Potts et al. 2010; Sánchez-Bayo and Wyckhuys 2019). One factor not widely considered is the possible role of anthropogenic electromagnetic radiation (EMR).

Electromagnetic fields (EMFs) are invisible electric and magnetic fields of force. All living organisms have evolved in Earth's natural EMFs and depend on them to live. Natural sources include Earth's static magnetic field, and static electricity, including differences in charges among clouds and the earth that can lead to lightning. Electromagnetic radiation (EMR) originates when fields change.

Anthropogenic (human-made, artificial) EMR sources are sometimes referred to as electromagnetic pollution or electrosmog. The main frequency ranges of interest in this article are: 1) extremely low frequencies (ELF) of 50/60 to 90 Hz that emanate from sources such as power lines and building wiring; and 2) radiofrequency radiation (RFR) of 700 MHz to 6 GHz, commonly used for devices such as cell phones, radio and television, and their supporting infrastructure, e.g., cell towers, antennae on buildings, and orbiting communications satellites.

Also discussed are frequencies currently being developed and deployed above 6 GHz for 5G (5th Generation) for faster and more pervasive connectivity, including the "Internet of Things".

There are no Canadian guidelines for non-ionizing EMR exposures for non-human organisms, including wildlife. Health Canada's safety guidelines, Safety Code 6 (Health Canada 2015), set limits for human exposure to RFR (3 kHz to 300 GHz). In the commonly used frequencies, these guidelines are based only on thermal effects, i.e., if there is no heating, it is assumed that there is no harm. For "far field" exposures such as cell towers and Wi-Fi access points, the Safety Code 6 power density safety limits are, depending on frequency, between 2 and 10 W/m2 [at least 1,000,000,000,000 (= 1012) x natural levels (Bandara and Carpenter 2018)]. For "near field" exposure, such as cell phones, the upper limit of the permissible Specific Absorption Rate (SAR) is set at 1.6 W/kg for the head, neck, and trunk.

What We Know

Relatively few EMR studies have been conducted on invertebrates. A 2011 report commissioned by the Indian Ministry of Environment and Forest found that of 919 publications identified in a comprehensive review of biological effects of RFR exposure, 81% (742) were on humans, about 3% (30) were on birds, and <1% (7) were on bees. "Other animals" made up about 12% (111), and <1% (8) were on plants (Expert Committee 2011). The majority of the studies in each of the categories showed impacts.

Invertebrates – Honey Bees

We conducted a comprehensive search for original (primary) peer-reviewed research studies on EMR (ELF and RFR) and honey bees using "EMF Portal", an online database of scientific studies on the effects of electromagnetic fields, created by Aachen University, Germany (EMF Portal 2019), as well as internet searches. Identified publications were further examined for relevant studies. A total of 26 studies were identified from 1976 to the end of January 2019. Research methods and descriptions varied widely in quality. No studies were conducted in Canada or by Canadian scientists. Some studies that found effects were noted as being conducted under "non-thermal" conditions.

Seven of the eight ELF frequency studies reported effects (Table 1). One paper concluded: "The results suggest that 50 Hz ELF EMFs emitted from powerlines may represent a prominent environmental stressor for honey bees, with the potential to impact on their cognitive and motor abilities, which could in turn reduce their ability to pollinate crops." (Shepherd et al. 2018). For RFR studies, 13 of 18 (72%) showed effects (Table 2). Exposure conditions ranged from ambient levels (two studies) to very high levels.

Invertebrates - Other insects

Potential adverse effects have been reported in other invertebrates (Cucurachi et al. 2013), including fruit flies (Sagioglou et al. 2016) and ants (Cammaerts and Johansson 2013). A major field study on insect pollinators (excluding honey bees) was conducted on two islands in the Mediterranean with cell towers (Lázaro et al. 2016). Abundance and composition of beetles, wasps, and hoverflies were negatively affected, and underground-nesting wild bees and bee flies were positively affected. The authors conclude: "… these changes …associated with electromagnetic smog may have important ecological and economic impacts on the pollination service that could significantly affect the maintenance of wild plant diversity, crop production and human welfare."

TABLE 1. Publications studying extremely low frequency fields (ELFs) and honey bees.

Study: authors and year Country of authors Effects*

1. Altmann and Warnke (1976) Germany Yes
2. Altmann and Warnke (1987) Germany Yes
3. Bindokas et al. (1988) US Yes
4. Greenberg et al. (1981a) US Yes
5. Greenberg et al. (1981b) US Yes
6. Kirschvink et al. (1997) US Yes
7. Shepherd et al. (2018) UK, Brazil Yes
8. Wyszkowska et al. (2019) Poland No

* Effects included disturbed flying behaviour, metabolism abnormalities, queen loss, and decreased overwintering survival.

TABLE 2. Publications studying radiofrequency radiation (RFR) and honey bees.

Study: authors and year Country of authors Effects*

1. Dalio (2015) India Yes
2. el Halabi et al. (2013) Lebanon Yes
3. Favre (2017) Switzerland Yes
4. Favre (2011) Switzerland Yes
5. Gary and Westerdahl (1981) US No

6. Harst et al. (2006) Germany Yes
7. Kimmel et al. (2007) Germany Yes
8. Kumar et al. (2013) India Yes
9. Kumar et al. (2011) India Yes
10. Mall and Kumar (2014) India No
11. Mixson et al. (2009) US No
12. Odemer and Odemer (2019) Germany Yes
13. Patel et al. (2016) India No
14. Pattazhy (2012) India Yes
15. Sahib (2011) India Yes
16. Sharma and Kumar (2010) India Yes
17. Taye et al. (2017) India Yes
18. Westerdahl and Gary (1981) US No

* Effects included production of higher frequency sounds; induction of piper signal (announces the warming process or is a signal of a disturbed colony); disruption of navigational skills of foragers; increased aggressiveness; reduction of numbers of returning foragers and in some cases, none returning (colony collapse). Other adverse effects included decreased colony strength, hatching success, queen egg-laying, honey storing ability, and pollen reserves.

An EKLIPSE project (a research initiative on biodiversity and ecosystem services, supported by the European Union Horizon 2020 research and innovation program) recently took an in-depth look at 39 peer-reviewed studies of effects of EMR exposure on invertebrates as part of a wider study on wildlife and exposure to EMR (Goudeseune et al. 2018). The EKLIPSE webinar presentation in January 2018 (Tscheulin and Vanbergen 2018) reported evidence that EMR provides environmental cues, can affect behaviour and reproduction, and poses a potential risk to some physiological mechanisms in invertebrates. Levels of confidence in the evidence were outlined in the webinar and in an EKLIPSE report (Malkemper et al. 2018) (Figure 1).

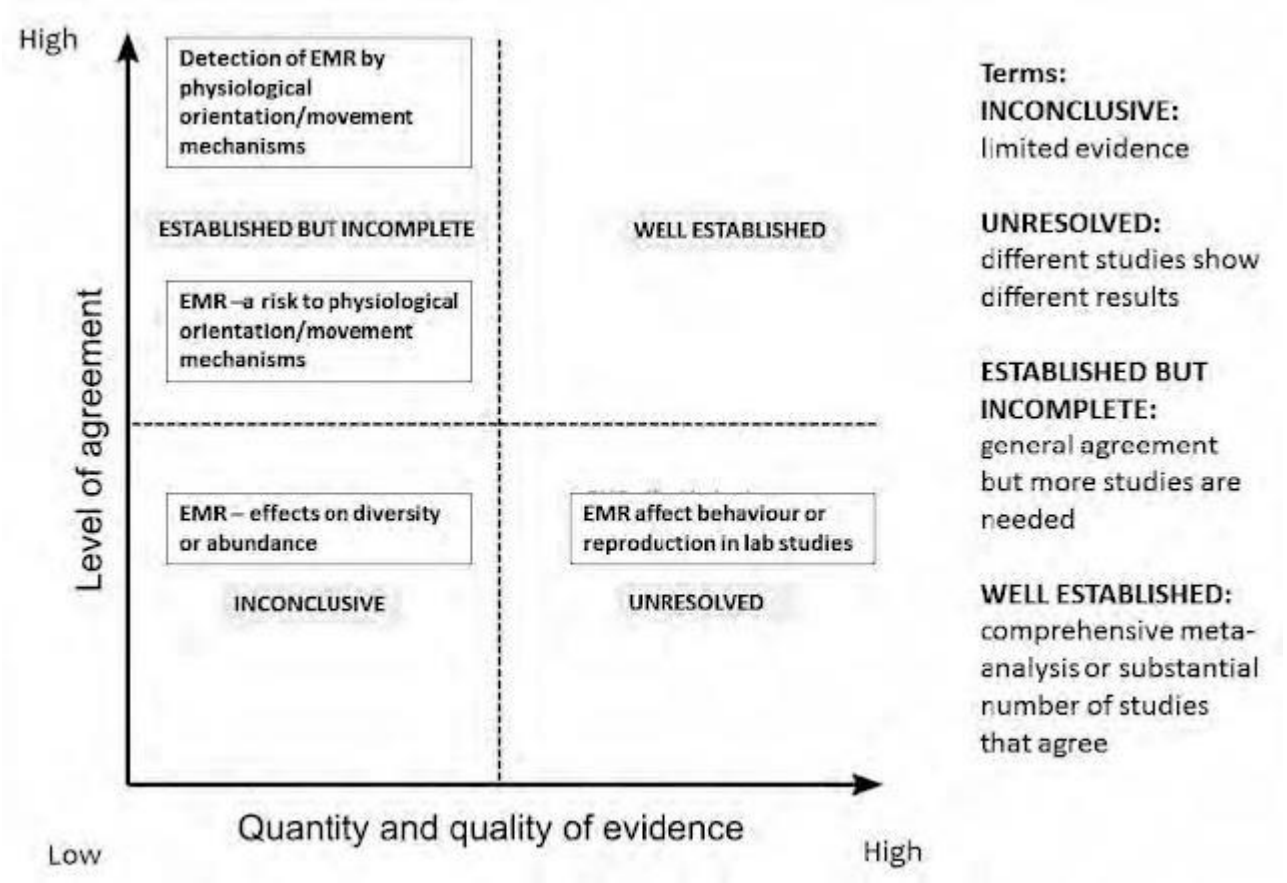

FIGURE 1. Levels of confidence of statements on invertebrates. Modified from EKLIPSE report (Malkemper et al. 2018).

Plants

A review by Halgamuge et al. (2017) identified 45 peer-reviewed publications (1996–2016), many conducted at non-thermal levels, where 90% showed physiological or morphological effects from exposure to RFR. Sensitivity varied with frequencies. Pea, tomato, and mungbean were very sensitive. In a partially replicated study, peas exposed to Wi-Fi frequencies had diminished growth compared with the controls after 30 days (Havas and Symington 2016). A study on trees concluded: "EMR from mobile masts are harmful to trees" (Waldmann-Selsam et al. 2016).

Vertebrates – Birds

Disorientation of some bird species due to exposure to ambient (non-thermal) RFR levels have been documented in a number of bird studies, most notably in the well-controlled, double blinded work on European robins by a German research team (Engels et al. 2014). Weak broadband fields disrupted the birds' magnetic compass orientation whereas relatively strong narrowband fields did not (Schwarze et al. 2016).

Domestic Animals

ELFs at low levels have been reported to affect behaviour in large mammals (Burda et al. 2009), and circadian rhythms and blood biochemistry in dairy cows (Stelletta et al. 2007).

Laboratory mammal studies

There are more than 1,000 studies showing potentially adverse effects at well below Safety Code 6 levels. Recently, a $30 million US study, conducted at frequencies commonly used in 2G and 3G cell phones, found "clear evidence of carcinogenic activity" in male rats (National Toxicology Program 2018). We examined 20 laboratory mammal studies conducted at Wi-Fi frequencies of 2400 to 2450 MHz that reported DNA damage, oxidative stress, and other potentially adverse effects at and well below the Safety Code 6 SAR level (Figure 2).

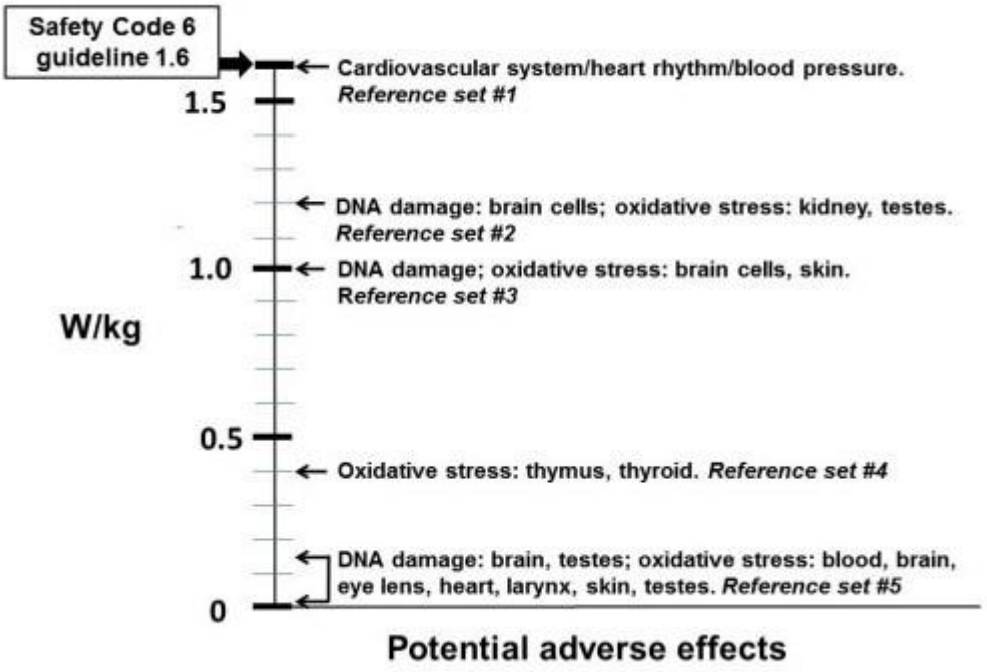

FIGURE 2. Potential harmful biological effects reported for Wi-Fi exposure in 22 studies with the corresponding Specific Absorption Rate (SAR) level indicated with arrows. Health Canada's Safety Code 6 SAR safety guideline is 1.6 W/kg (head, neck, and trunk). References for the respective sets are:

Reference set #1: Saili et al. (2015)
Reference set #2: Lai and Singh (1996); Özorak et al. (2013)
Reference set #3: Ceyhan et al. (2012); Eser et al. (2013); Paulraj and Behari (2006)
Reference set #4: Misa Agustiño et al. (2012); Misa-Agustiño et al. (2015)
Reference set #5: Atasoy et al. (2013); Aynali et al. (2013); Deshmukh et al. (2013); Deshmukh et al. (2015); Gürler et al. (2014); Kesari et al. (2010); Meena et al. (2014); Nazıroğlu et al. (2012); Oksay et al. (2014); Shahin et al. (2014); Shahin et al. (2013); Tök et al. (2014)

Vertebrates – Humans

The International Agency for Research on Cancer of the World Health Organization (IARC-WHO) classified ELF magnetic fields as a Group 2B possible human carcinogen in 2001 (IARC 2002) and RFR (includes Wi-Fi frequencies) in 2011 (Baan et al. 2011). This latter classification was based mainly on human epidemiological studies showing an elevated risk of brain tumours (gliomas).

Canadian data shows a doubling of risk for gliomas for those using cell phones for more than 558 lifetime hours (Momoli et al. 2017). More recent studies support upgrading the classification to a probable or known human carcinogen (the same classification group as asbestos and tobacco) (Coureau et al. 2014; Miller et al. 2018; Peleg et al. 2018).

Proposed mechanisms

Underlying mechanisms for the various effects have been proposed: 1) magnetic compass (orientation) is affected (Engels et al. 2014); 2) increased oxidative stress (therefore more susceptible to disease and other insults) (Reuter et al. 2010; Yakymenko et al. 2016); and 3) activation of voltage-gated calcium channels (Pall 2016).

5G (5th Generation: 6 GHz and higher frequencies)

Very few studies on any taxa have been conducted using higher frequencies in the millimeter wave 5G range. These frequencies are of particular concern because the wavelengths are in the same range as some invertebrate body sizes and structures such as antennae. In insect modelling studies, all insect models absorbed from 3 to 370% more radiofrequency power at and above 6 GHz frequencies than at lower frequencies (Thielens et al. 2018). The proposed infrastructure will be dense with mini-antennae (microcells) required every 100 to 300 meters (FCC 2016a). Public health issues and environmental implications are discussed in Russell (2018).

RFR emissions from orbiting satellites

According to the United Nations Office for Outer Space, currently there are over 7,000 “objects” orbiting Earth (United Nations 2018), with numbers expected to increase. Many of these satellites are transmitting or receiving RFR signals. SpaceX alone has made applications to the US Federal Communications Commission (FCC) to position more than 300 satellites over the next few years (FCC 2016b)1. With emissions from orbiting satellites, there will no longer be “unexposed” groups of living organisms that can serve as controls in research field studies.

What We Don’t Know

There are substantial gaps in knowledge regarding biological effects on ecosystems of the frequencies and modulations now commonly in use. In addition, there is little known about non-linear effects and “windows” of vulnerability (Marino et al. 2000; Sage 2015; Sagioglou et al. 2016) as well as synergistic effects (combined, co-exposures) (Kostoff and Lau 2013).

The following points to address knowledge gaps are largely taken from the EKLIPSE project (Goudeseune et al. 2018):

1) Develop standardization/methodologies/protocols to design better future studies and the ability to compare research results;
2) Set up more field and ecological studies, along with better corresponding laboratory studies;

3) Initiate research on more technologies;
4) Study the impacts of EMR at different biological organizations/levels;
5) Collect data on confounding/interfering factors and how multiple frequencies interact;
6) Develop more and better collaborations, especially interdisciplinary teams;
7) Include observations and knowledge from local people and consider citizen-science approaches.

What We Need to Know

We need a fuller understanding of the impacts of EMR on invertebrates specifically and how EMR effects could impact ecosystems in general. This includes knowledge regarding the frequencies and modulations already deployed and ahead of, or at least alongside, wide deployment of new technologies such as 5G.

In Canada we need:

1) Biologically based EMR exposure guidelines for wildlife based on thermal and, in particular, non-thermal biological effects;
2) Research as outlined by the EKLIPSE report; and
3) Adequate funding of independent scientists to conduct research.

A final consideration is that scientists who are conducting ongoing and future biological and ecological research, particularly field studies, should be supported with expert advice and equipment, so they can use the opportunity to include EMR measurements in research protocols.

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1 According to an October 15, 2019 article (https://spacenews.com/spacex-submits-paperwork-for-30000-more-starlink-satellites/), "SpaceX…filed paperwork in recent weeks for up to 30,000 additional Starlink satellites on top of the 12,000 already approved by the US Federal Communications Commission."

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