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Review

Biological effects of electromagnetic fields on insects

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Abstract

Worldwide, the number of insects is decreasing at an alarming rate. It is known that among other causes, the use of pesticides and modern agricultural practices play a particularly important role. The cumulative effects of multiple low-dose toxins and the spread of toxins in nature have not yet been methodically researched, or only in the early stages.

Existing research indicates another factor of anthropogenic origin, which might cause subtle adverse effects: the increasingly frequent use of artificial electromagnetic fields (EMF) such as high voltage, mobile telephony and Wi-Fi. The infrastructure of the next generation of mobile communications technologies, 5G, is being deployed without having been previously tested for possible toxic effects. With mankind's aspirations for omnipresence of technology, even modest effects of electromagnetic fields on organisms might eventually reach a saturation level that can no longer be ignored.

This systematic review evaluates the state of knowledge regarding the toxic effects of electromagnetic fields (EMF) on insects. Also included is a general review of reported effects and mechanisms of EMF exposure, which addresses new findings in cell biology. 72 of 83 analyzed studies found an effect. Negative effects that were described in studies include: disturbance of the sense of orientation, reduced reproductive ability and fertility, lethargy, changes in flight dynamics, failure to find food, reduced reaction speeds, escape behavior, disturbance of the circadian rhythm, blocking of the respiratory chain and damage to the mitochondria, misactivation of the immune system, increased number of DNA strand breaks.

Some mechanisms of action leading to these damages are identified. EMFs affect the metabolism, among other things affecting voltage-gated calcium channels, e.g. in neurotransmission and in muscle tissue, which can lead to an overactivation of signal transduction and of the respiratory chain with production of free oxygen radicals and consequently leading to oxidative cell stress.

The results show that EMF could have a serious impact on the vitality of insect populations. In some experiments it was found that despite low levels of exposure to transmitters, harmful effects occurred after several months. Field strengths 100 times below the ICNIRP limits could already have effects. Against the background of the rapid decline of insects and the further expansion of high-frequency electromagnetic field sources, there is not only an urgent need for further research, but also in particular on the interactions with other harmful noxious agents, such as pesticides. When planning the expansion of mobile networks, insect habitats should be protected from high-intensity EMF exposure already now.

1. Biological effects of electromagnetic fields (EMF)

The recently publicly announced insect decline, the beginnings of which go back several decades, seems to be caused by a multitude of factors with cumulative effects (Hallmann et al. 2017; Sánchez-Bayo and Wyckhuys 2019, Fig. 1). Although it is assumed that the main causes are to be found in the use of pesticides and in the restructuring or destruction of natural habitats, additional negative effects of other kinds cannot be excluded – e.g. the effects of hormone-like substances, heavy metals and electromagnetic fields, all factors whose occurrence in nature has drastically increased in recent decades (Sharma et al. 2016; Rhind 2009; Bandara and Carpenter 2018).

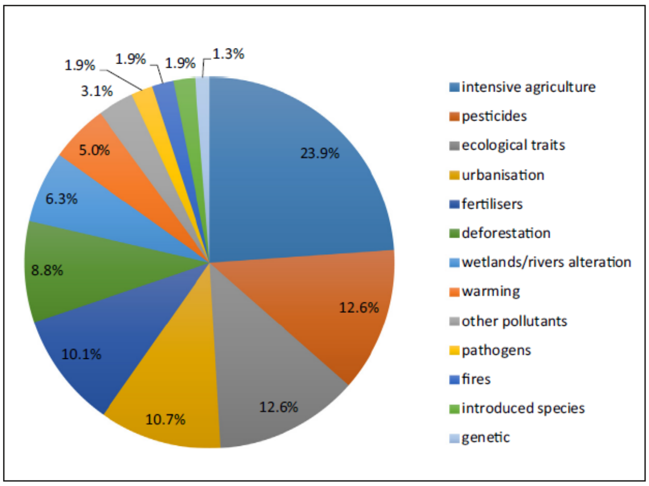

Figure 1: Main causes of recent insect decline.
Source: Sánchez-Bayo and Wyckhuys 2019

This review deals primarily with the effects of low- and high-frequency electromagnetic fields on insects. The effects of low-frequency magnetic fields (and EMF) from power lines (at 50 Hz power frequency) have been relatively well studied already, e.g., in terms of incidence of leukemia in humans (ARIMMORA final report 2015), or toxicity to insects (Wyszkowska et al. 2016; Maliszewska et al. 2018; Shepherd et al. 2018).

High voltage and mains electricity became standard in Europe from 1950 onward. Less well researched are the newer, high-frequency electromagnetic fields (HF-EMF) in the microwave range, as used for mobile phone networks, but also Wi-Fi and similar applications (from 1990 on). In the case of low-frequency EMF, adequate experimental devices to apply the characteristic EMF to organisms in the laboratory, so-called Helmholtz coils, have existed for decades. Hereby the field strength can also be adjusted. In comparison, there are no adequate emulations for high-frequency EMF, such as those emitted by mobile phone towers or Wi-Fi routers – or they are very expensive and/or require a permit (mobile phone repeaters). The most realistic approach at the moment is to use mobile phones as emulation of mobile phone masts for laboratory tests, and actual Wi-Fi routers.

Since we are about to develop the next generation of mobile phones (5G), whose infrastructure could include a further increase of radiated energy in the urban sector, the safety of this technology should be demonstrated in advance - as is inevitable when marketing new drugs (Bandara and Carpenter 2018).

In general, a distinction is made between thermal and non-thermal biological effects of electromagnetic fields. The thermal effect is based on direct heating of tissue (as in a microwave oven). Below the intensities where tissue heating can be measured, several additional non-thermal effects have been described, e.g. microwave hearing (in humans), also known as the Frey effect, whose mechanism has been known for several decades (electroelastic transformation of microwaves into sound waves in the skull, see Chou, Guy, and Galambos 1982; Belyaev and Markov 2015).

Furthermore, parametric resonance, which is accompanied by a change of the human and animal electroencephalogram, is regarded as scientifically proven (Hinrikus et al. 2017; Mohammed et al. 2013). There is increasing evidence that parametric resonance is a by-product of the activation of voltage-gated ion channels and is associated with calcium release (Agnati et al. 2018; Pall 2016; Sun et al. 2016; Belyaev and Markov 2015) – and thus affects all animal and plant organisms.

In summary, it could be said that biological effects of chronic EMF exposure follow this general pattern: EMF act (directly or indirectly) on voltage-gated calcium channels (VGCC), opening them and leading to calcium release.

More precisely, voltage-gated ion channels (Na^+, K^+), as well as the NMDA receptor, seem to be sensitive to non-thermal (i.e. very low) EMF levels and this is probably related to useful functions of the perception of endogenous EMF ("ephaptic coupling"), which are produced by the activity of neurons and astrocytes (Martinez-Banaclocha 2020; Chiang et al. 2019; Hales and Pockett 2014). Thus, the mechanism of ephaptic coupling seems to play an active role in the synchronous activity of heart cells (Weinberg 2017), as well as in the olfactory processing of odorant mixtures (antennas or olfactory nerve) (Zhang et al. 2019; Bokil et al. 2001), and also in the coordination of movement in the cerebellum (Han et al. 2018).

In these cases, however, voltage-gated sodium channels (Weinberg 2017; Han et al. 2018), potassium channels (Fogle et al. 2015) or NMDA receptors (Chiang et al. 2019) – which are voltage-sensitive and channel sodium and calcium ions – have been shown to be the macromolecules directly affected by EMF. In addition, it is assumed that astrocytic calcium waves, through ephaptic coupling, influence and regulate neuronal activity over wide areas and to a large extent (Agnati et al. 2018; Martinez-Banaclocha 2020).

The EMF-induced activation of voltage-gated sodium and potassium channels or NMDA receptors leads indirectly, by triggering or amplifying action potentials, to increased activation of synaptic VGCC and release of calcium (Pilla 2012); neurotransmission based on action potentials via chemical synapses requires activation of VGCC (Atlas 2013).

Calcium is one of the most common secondary messengers in all organisms, and elevated levels of calcium have an activating effect, e.g. on the respiratory chain and muscle (Kim et al. 2019). Calcium in turn releases nitric oxide (NO) via calmodulin. An overactivation of calcium-dependent neurotransmission (and possibly metabolic pathways) leads to the production of free oxygen radicals (reactive oxygen species, ROS) such as peroxynitrite, i.e. to oxidative stress.

Chronically increased oxidative stress has a toxic effect on organisms in many different ways, e.g. by blocking the respiratory chain, causing damage to mitochondria, misactivation of the immune system and an increase in the genetic mutation rate (Valko et al. 2007; Saliev et al. 2019).

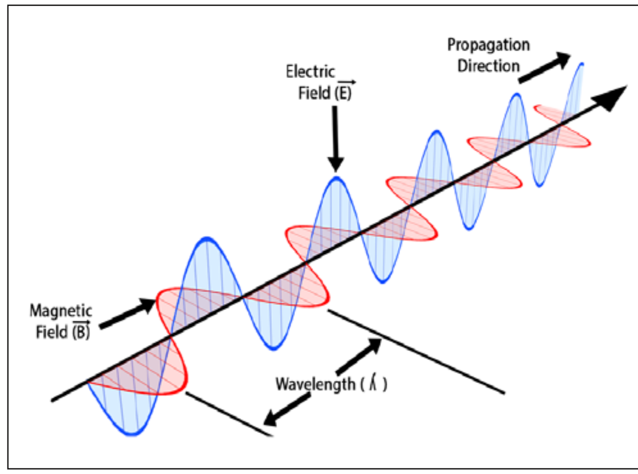

Figure 3: Electromagnetic wave. Electric field strength in blue, magnetic field strength in red. The radiation intensity or power density of an EMF can be derived from both field strengths (see appendix).
Source : https://byjus.com/physics/characteristics-of-em-waves/

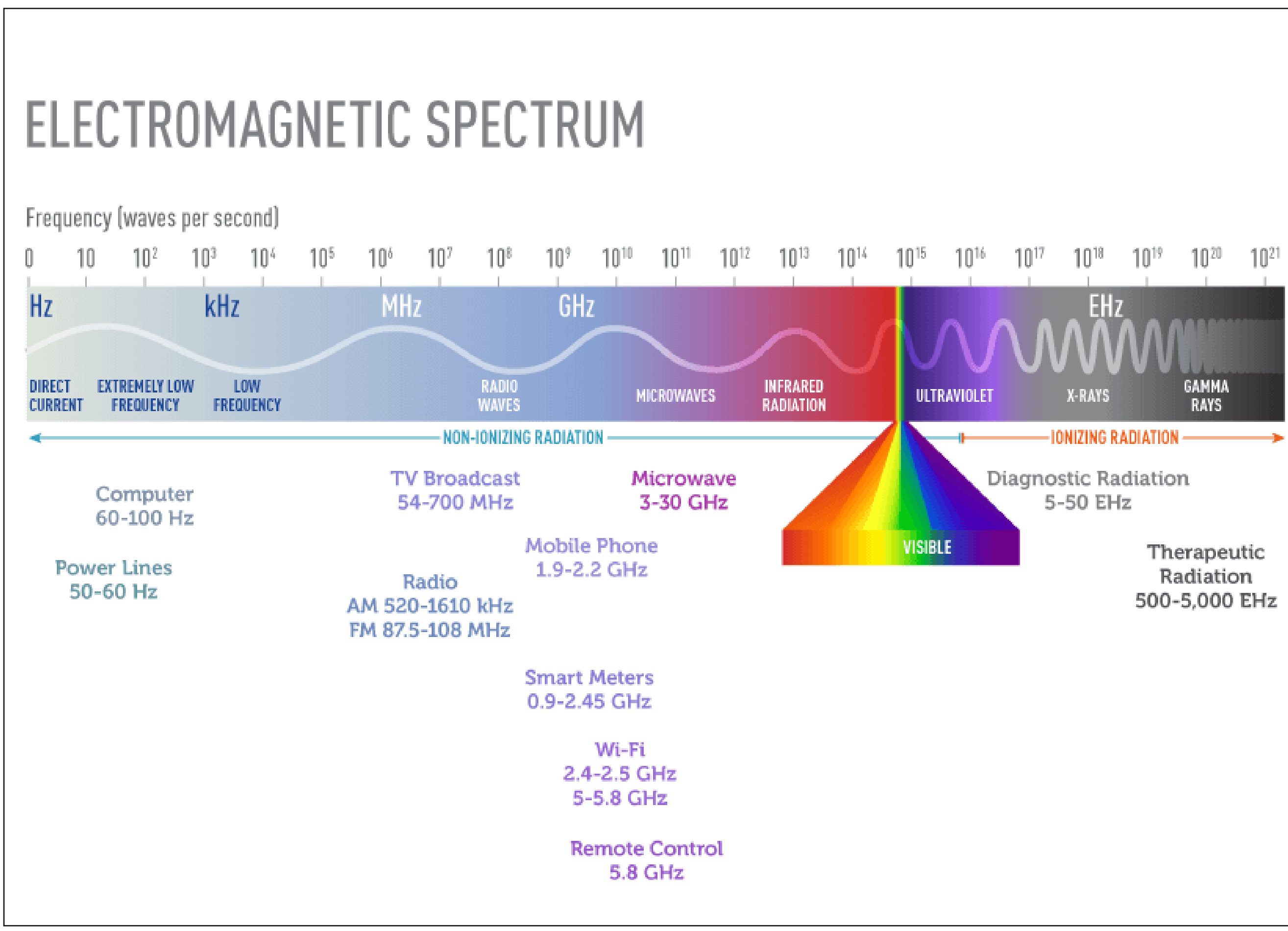

Figure 2: Electromagnetic spectrum. Source: https://thinktankgreen.com/emf-testing/facts-education/electromagnetic-spectrum/