Sham or reasons for concern?
The influences of electromagnetic fields on honeybees

Science shop Wageningen UR
Nov-Dec 2010

Carolina Urrea Hernandez;
Coretta Jongeling;
Hanneke Rouw;
Marloes van Loon;
Erik Koenen;
Sebastien Beguerie.

Edited by **Tjeerd Blacquière[1] & Hugo Hoofwijk[2]**

tjeerd.blacquiere@wur.nl hugo.hoofwijk@groenelink.nl

[1]Bees@wur, Plant Research International, Wageningen UR

[2]De Groene Link, Wageningen

Account

This report has been prepared by a group of six master students of Wageningen University, Department of Plant Sciences, presenting the results of their Academic Consultancy Training program in November-December 2010. Towards finalization of the report, it has been edited by Tjeerd Blacquière and Hugo Hoofwijk, with the assistance of several independent experts.

Although the editors have attempted to present an objective and unbiased summary of the state of the art on the subject, the report may still contain some errors or omissions. For that matter the editors invite the readers to draw their attention to any possible improvements, which can be incorporated in any future revision of this report.

Further distribution of the report and citation are encouraged, provided that the source is properly cited:

Blacquière T & Hoofwijk, H (Editors) 2011 Sham or reasons for concern? The influences of electromagnetic fields on honeybees. Report WUR Science shop & DLO (Praktijkonderzoek Plant & Omgeving/Plant Research International). 54 pages.

Disclaimer

Table of Contents

Summary

In this report, we present the results from a literature study on the effects of electromagnetic fields (EMF) on honeybees. This literature study was carried out as part of a bigger project of the Science Shop, acting upon a request from the Dutch Nationaal Platform Stralingsrisico´s (‘national platform for radiation risks’). The aim of the project was to get an insight in whether or not honeybees are harmed by EMF. This appears complicated to us, as we think that the current literature on this topic is of questionable quality.

Possible health effects of exposure to EMF on humans, but also on animals, are heavily debated, both in the scientific community and in society. Some of the groups in this public debate (e.g. advocacy groups concerned about radiation, phone companies) have opposed interests, and this may result in biased information about the topic. In this report, we not only wanted to give an overview of the current literature on effects of electromagnetic radiation, but also judge the quality of the information. Criteria to judge literature were a.o. background of the authors, appropriateness of material and methods, the nature of the results and use of references. Next to this, also the facts in the studies were evaluated.

In order to do this, we first emerged ourselves in some basic information about electromagnetic fields, radiation and types of effects of radiation. Electromagnetic radiation is a very broad definition, and includes many types of radiation ranging from electric waves to gamma rays. Some of these types of radiation have no (known) effects, while others (e.g. X-rays) are known to cause health problems. These effects can be thermal and non-thermal, i.e. caused by heat generated by the radiation, or by other, less understood mechanisms. We also give background information about bees and colony losses in bees. Colony losses in bees have received much attention the last few years. Some people claim a new type of colony losses, CCD, is putting the bees at risk worldwide. EMF is mentioned as a possible cause, amongst other such as pathogens and pesticides. Combining the information about radiation, bees, and also information from research on other animals, we wanted to look at hypothetical effects of EMF on honeybees. So: how *could* bees be harmed by EMF? In this, we focus mainly on navigation in bees, as this seems to be the most realistic way in which bees could be affected by EMF.

Studies on other organisms show that EMF can have both thermal and non-thermal effects in living systems. *Drosophila* is shown to be adversely effected in reproduction and development, this could also be the case in honeybees, as their development is similar. In studies on birds, negative effects on their navigation were also found, so this also provides clues for the honeybee case. Honeybees, just like birds, use among other magneto reception for orientation and navigation. The most important cue for honeybees in their navigation is the sun's position, but also landmarks are used. The importance of magnetoreception is unknown and it is not yet clearly understood overall. However, magneto receptors (magnetite and cryptochrome) are found in honeybees and they do respond to changes in the Earth magnetic field. Therefore, the hypothesis that EMF could influence their behaviour does make sense.

Scientific studies show local adverse effects from high tension power lines on bee colonies, including stinging behaviour and electric shock when the bees are in contact with a conducting medium, and especially around the entrance of the hive.
Some studies were done on effects on the waggle dance by interference with the Earth magnetic field. Bursts of artificial low-frequency fields induced misdirection in the waggle dance, while compensation of the Earth magnetic field resulted in a lower dance tempo.
There is a complete lack of reliable information on the effects of radio frequency EMF on honeybees. A couple of publications from a German group (University of Koblenz-Landau) deal with the influence of DECT-phones. The experimental set-up is found by us to be inappropriate with a low number of observations and many other flaws. A study from two Indian researchers (Panjab University) had an even lower number of colonies that were studied and the authors seem to us biased as they strongly give their opinion in the article. Another publication that deals with radio frequency radiation effects on honeybees is a brochure from the Kompetenzinitatieve (a German advocacy group), written by Dr.rer. nat. U. Warnke. It is presented as a review of the scientific information that is available, but was actually to our opinion highly unreliable and biased.

Because of the clear knowledge gaps, no conclusions can be drawn on the question whether or not EMF is harmful to honeybees. We can also not conclude if EMF is a (contributing) cause of colony losses and/or CCD or not. Clearly, more research is needed to answer these questions.
We recommend that in further studies, the experiments should be carefully set up and that measurements and observations should be done in appropriate ways. This would lead to more reliable and comparable results. Studies on effects of radio frequency radiation on the waggle dance are recommended, as there might be an influence there as was already shown by studies with low-frequency radiation. Lastly, it is recommended that proper communication of the results to the public should be taken care of, to end the circulation of a lot of speculative information.

1. Introduction

In the last few years, the use of products that produce electromagnetic fields has been increasing rapidly, and it is still increasing. Examples of these products are mobile phones, Wi-Fi, and electricity poles. The increasing use of these products has led to a public debate about possible harmful effects of electromagnetic fields (EMF) on for example human health, but also on honeybees (e.g. Aldrich and Easterly, 1987; World Health Organization, 2010b). EMFs are mentioned as a cause of honeybee colony losses, the sudden disappearance of honeybees, which is a huge problem in the field of beekeeping (vanEngelsdorp *et al.,* 2009). These losses are problematic both from the ecological and human point of view (production of bee products, crop pollination, biodiversity, etc.) (Blacquière, 2009). However, the influences of EMF on honeybees have not been studied thoroughly. There is a lot of information available on the topic. However, the question is how valuable this information is. As a consequence, it is difficult to get an insight in whether or not honeybees are harmed by electromagnetic fields. To solve this problem we have tried to answer several questions in this report. The first question is, what is the quality of the available literature? We have divided this question in several sub questions.

1) What are criteria to judge the quality of information?
2)What are criteria to judge the quality of research/methodology?
3) How to define the threshold between usable and useless information?

The second question we addressed in this report is, when looking at the biology of honeybees, how *could* bees theoretically be harmed by electromagnetic fields? This question can be divided in:
1) Which effects of EMF on bees have been reported?
2) Which effects of EMF on bees have been proven?
3) If bees are harmed, how would these effects relate to colony loss?
4) How important is EMF compared to other harms (viruses, pesticides etc.)?
5) Are related species harmed by EMF, and how?

The last question we like to answer in this report is, what can be concluded about the effects of electromagnetic fields on honeybees, based on the available literature?

Nationaal Platform Stralingsrisico's (national platform radiation risks) is concerned about EMF in the environment and possible health risks for humans and animals. The Nationaal Platform requested a project to the Science Shop of Wageningen UR to try to find out whether or not scientific evidence can be found for negative effects of EMF on honeybees. The Science Shop supports non-profit organizations by implementing research projects with a potential societal impact in the fields of nutrition and health, sustainable agriculture, water management, environmental quality, and processes of social change. A part of the project mentioned above is a literature study, which was commissioned to us.

1.1 Objective

The objective of this project is to understand more about if, and how honeybees are harmed by EMF. To accomplish this, we have set several aims. The first aim is to gain knowledge on possible harmful effects of EMF on honeybees. To do this, we want to determine the value of the available information. We want to specify knowledge gaps concerning this topic. Moreover, we want to make recommendations for further research, and the last aim is to give an alternative for speculative information made by non-experts.

1.2 Methodology

In this project, we have conducted a literature study. Our goal was to provide a literature review, and an overview of the state-of-the-art knowledge of the topic. This encompasses the retrieval of literature that is relevant to the problem, assessing the quality of the literature and combining the information into a text that deals with true knowledge, concerns of various stakeholders involved and critique of unreliable findings. The methods we used for these aspects are further elaborated below.

Information retrieval

For most of the scientific literature on the subject, we made use of the library services (access to bibliographic databases and scientific journals) of Wageningen University. Databases that were used are:

1. Scopus (multidisciplinary)
2. Web of Science (multidisciplinary)
3. Agris (agricultural bibliographic database)
4. Biological Abstracts
5. CAB abstracts (publications in disciplines of 'life sciences')
6. Zoological Record

Next to searching in databases we also used the reference list of the articles we already found.

Moreover, various other internet resources were used, like the official websites of involved stakeholders (organizations that either are concerned about EMF in the environment or skeptic on possible effects or even those that are promoting positive effects of EMF).

Quality assessment

There appears to be a lot of literature of questionable quality on the topic, so a decent evaluation of the quality of each publication is crucial. We have looked into relevant aspects of honeybee biology and apiculture (i.e. colony collapse disorder, the way in which bees navigate) and EMF (i.e. what EMF is, and effects on other organisms), in order to be able to judge correctness of the content of the articles, and understand if research questions and methods were appropriate.
Scientific literature was most important for the project and we tried to address all the literature on EMF and honeybees. Our goal was to assess whether or not these publications provide useful insights into the topic. Much of the research could have been influenced by various stakeholders or the researchers involved could be biased as well. We therefore assessed the appropriateness of experiments that were conducted (for example was it done blind or double blind) and the accuracy of the presentation and discussion of the results. An elaborate description of the criteria we used to do this can be found in appendix I. We looked into the scientific methodology that was used: whether it was hypothesis-driven and directed towards falsification rather than that proof for a certain case was tried to be found. Clues on the objectivity of the research involved can be provided by author affiliations or information on the funding bodies involved. The expertise of the authors and researchers was assessed. Also, the background knowledge that we acquired through studying honeybee biology, information on apiculture and EMF was useful to see if the results and conclusions of publications actually made sense. We have put effort in remaining objective ourselves, at all times. Group members attended each other on this when objectivity appeared to be decreasing.

In this report, we will first present some background information on EMF in chapter 2. An overview of the public debate on the effects of EMF on health and on honeybees will also be given in this chapter. At the end of this chapter an analysis of the involved stakeholders will be given. In chapter 3 we will give some general information on the biology of bees, the uses of bees and on colony losses. In the next chapter we will look at the effect of EMF on other organisms to determine if, an how this could relate to possible harmful effects in bees. Navigation of bees is also addressed in this chapter. In chapter 5, an evaluation of the scientific literature and other information sources on the effect of EMF and honeybees will be given. Lastly, in chapter 6, conclusions will be given, the state of the art about the influences of EMF on honeybees will discussed, as well as recommendations for future research.

2. Electromagnetic fields and concerns

Along with the increase in the use of electronic devices, there has been more and more concern about the health risks associated with exposure to EMF (Aldrich and Easterly, 1987 and World Health Organization, 2010b). Some people are concerned about possible harmful effects of EMF on health. This concern is largely based on a variety of self-reported health problems (European Commission, 2009).

The public health concerns arose around 1970, when reports from Russia suggested that workers in electrical substations suffered from diverse symptoms that might be related to their job (Aldrich and Easterly, 1987). In 1973, Robert Becker evaluated some experiments on possible effects of non-ionizing EMF caused by the large antenna system that the Navy had funded. He was the first person to mention his concern in the USA (MAE-WAN HO institute of science in society, 2004). Since 1979, more reports have been published which suggest that there might be chronic health effects related to exposure to electrical fields (Aldrich and Easterly, 1987).

A survey by the Euro barometer with around 30,000 EU citizens found that the opinion towards the potential health risks of EMF is evenly divided, 48% is concerned and 49% is not concerned. 80% of the citizens feel that they are not informed on the existing protection framework related to the potential health risks of EMF. As potential sources of considerable health effects, high-tension power lines are most cited (37%), followed by mobile phone base stations (36%) and handsets (28%) (European Commission, 2007a).

2.1 What is EMF?

Electromagnetic radiation (EMR) can be defined as energy propagated through space that exhibits wave-like behavior (in fact it consists of particles, quanta, that oscillate when moving through space). Electromagnetic fields (EMF) are physical fields that are produced by a source of EMR. Electric fields are associated with electric charge and magnetic fields with the movement of electric charge. Both quickly decrease in intensity as the distance to the source increases. EMF can be natural and man-made. Electromagnetic waves exist in a continuous spectrum of wavelengths/frequencies (Figure 2.1). The shorter the wavelength, the higher the frequency. Frequencies are expressed in Hertz (Hz). At low frequencies (below 1 THz), electromagnetic waves are referred to as non-ionizing electromagnetic fields. Above that is the spectrum of optical radiation that includes infrared, visible light and UV-light. EMR with frequencies above that of UV-light (like X-rays and gamma-rays) is known as ionizing radiation. Non-ionizing radiation above 100 kHz can induce thermal effects. Ionizing radiation contains even more energy, it has quite different biological effects than non-ionizing radiation. It can ionize atoms (removing electrons from it) and break chemical bonds, and can therefore modify (organic) molecules. (Alpen, 1998; Vecchia *et al.*, 2009). This report deals with effects of non-ionizing electromagnetic fields, especially those in the radio frequency (RF) spectrum (30 kHz to 300 gHz). Mobile phones and base stations (GSM and UMTS, 900, 1800 and 2100 Mhz), DECT-phones (1900 MHz) and WiFi (2400 MHz) emit RF-radiation used for communication that is present in the environment (the latter two mainly in urban areas). Other electric devices and high tension power lines emit so-called extremely low-frequency (ELF, 50 Hz) radiation (Alpen, 1998; Natascha Staats, pers. comm.) and form another source of man-made EMF in the environment. Natural sources of low frequency magnetic fields include electrical charges in the atmosphere that are associated with thunderstorms and the Earth magnetic field. The latter is used for navigation with a compass as well as by various animals (e.g. fish, birds and honeybees) as is discussed in greater depth in the next chapter.

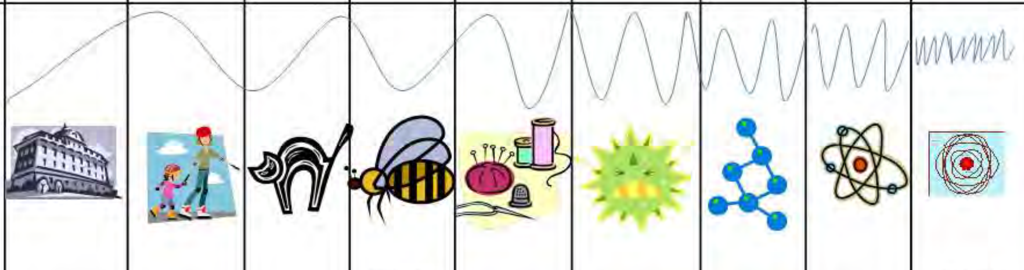
Type of	NON IONIZING SPECTRUM							IONIZING SPECTRUM	
Wave type									
	Electric waves	TV	Microwaves		Infrared	Visible Light	Optical UV	X-Rays	Gamma-Rays
Frequency (Hertz-Hz)	50	10^{3}	$5x10^{5}$	10^{8}	10^{12}	10^{15}	10^{16}	10^{18}	10^{20}
About the size of									
	Buildings	Humans	Cat	Honey Bee	Pinpoint	Protozo.	Molec.	Atoms	Atomic Nuclei
Wave Length (meters-m)	$6x10^{3}$	300	0.6	10^{-2}	10^{-5}	$0.5x10^{-6}$	10^{-8}	10^{-10}	10^{-12}

Figure 1. The electromagnetic spectrum, adapted from NASA (2010) and EMF Explained Series (2010).

To quantify electromagnetic field strengths, both the electric and magnetic components need to be measured. Electric field strength (E) is measured in volts per meter (V/m) and magnetic field strength (H) is measured in amperes per meter (A/m). Another way of quantifying the magnetic field strength is by measuring the magnetic flux density (B), which is expressed in Tesla (T). This is most often used, although it is perfectly all right as well to measure field strength in A/m. High frequency electromagnetic fields are often quantified in terms of power flux density (S) expressed in watt per square meter (W/m^{-2}) when measuring in the far field of antennas.

Furthermore, the frequency of electric magnetic fields is expressed in Hertz (Hz) (Vecchia *et al*., 2009).

There are three methods with which external electromagnetic fields can be measured, portable survey instrumentation, spectrum analyzers and personal exposure monitors. Portable survey instruments can be used to measure electric and magnetic field strengths. The limitations of these instruments include a relative spectral insensitivity, a slow response time and the lack of information on the frequencies, this can be overcome by the spectrum analyzers. Personal monitors are specific, the type of monitor used depends on the environment in which people are exposed (Vecchia *et al*., 2009).

Measurements of EMF can be influenced by different aspects such as the power of and distance to the source, physical environment of the fields, frequency of the radiation as well as possible modulation, reflection or polarization (Vecchia *et al*., 2009)**.** Thus, measurements and experiments related with electromagnetic fields are complex because there are many variables that can affect the final results of the experiments.

Thermal effects

When discussing effects of EMR in living systems it is mentioned that EMR can interact with cells and tissues in different ways, depending on the frequency, waveform, strength of field and the absorbed energy in biological systems. When an electromagnetic beam passes through tissue or other absorbing matter, part of its energy is absorbed (Alpen, 1998), causing thermal effects. In the case of ionizing radiation (like X-rays), that energy is strong enough to excite or ionize biological molecules and it can thereby cause damage. In non-ionizing radiation the energy is lower due to a lower frequency (and longer wavelength). For these types of radiation, including radio frequencies as employed in mobile communication technologies, the intensities will have to be much higher to have any effects caused by energy absorbance. For mobile phone use, the exposure level in humans is often quantified by the Specific Absorbance Rate (SAR), which is dependent on the shape and size of the absorbing body part, usually the head. Although there is a lot of controversy, and long term effects of current exposure levels are unknown, regular mobile phone use does seem to cause only limited thermal effects on the human body (Vecchia*et al*., 2009). The EU has set exposure limits (see Table below), below these limits thermal effects should not occur. If we would then consider honeybees, thermal effects will only be thought to occur when a bee is exceptionally close to a mobile phone or other radiation source. In case a mobile phone or receiving device is placed in a beehive as is done in some experiments, thermal effects can be expected, both from the device itself as through radiation. EMR from mobile phone base stations travels mainly horizontally, so the intensity is highest at approximately 150 m from the base stations. Because the intensity quickly drops with the distance to the source, the intensity at ground level is low (below EU-limits, Milieu Centraal, 2010; WHO, 2010), so thermal effects can be expected to be small or absent in natural situations.

Table. EU exposure limit values (f = frequency in Hertz).

Frequency range	Current density for head and trunk J (mA/m²)	Whole body average SAR (W/kg)	Localized SAR (head and trunk) (W/kg)	Localized SAR (limbs) (W/kg)	Power density S (W/m²)
Up to 1 Hz	40	-	-	-	-
1 – 4 Hz	40/f	-	-	-	-
4 – 1000 Hz	10	-	-	-	-
1000 Hz – 100 kHz	f/100	-	-	-	-
100 kHz – 10 MHz	f/100	0.4	10	20	-
10 MHz – 10 GHz	-	0.4	10	20	-
10 – 300 GHz	-	-	-	-	50

Source: Directive 2004/40/EC of the European Parliament and of the Council of 29 April 2004.

Non-thermal effects

Next to the thermal effects other effects of electromagnetic fields are often suggested, the so-called non-thermal effects. These effects are much less understood. The term refers to any effect that is not due to heating, so the definition is also rather vague. In the next chapter, some studies that have tried to investigate possible non-thermal effects on living organisms are discussed.

Current guidelines of human exposure are based on thermal effects because thermal effects are the dominantly established mechanism of health and biological effects of radio frequency exposure (Vecchia *et al*., 2009). However, it is not proven that radio frequency exposure within safety levels does not cause non-thermal effects and therefore many organizations do not agree with these guidelines.

2.2 Public debate

Several groups are involved in the public debate about the effects of EMF on health and environment. These include amongst others policy makers, users of EMF products, advocacy groups that are concerned about EMF risks (e.g. the Dutch National Platform on Radiation Risks), companies that sell products to reduce EMF (e.g. Mobichip pxd), companies that produce and sell communication technologies that emit EMF (e.g. Nokia and Ericsson) and scientists. The vision of the scientific community will be discussed in the following chapters.

Policy makers

The Dutch Government takes into account the opinion of the Gezondheidsraad (the Dutch health advisory body, www.gezondheidsraad.nl) and Kennisplatform Electromagnetische Velden en Gezondheid (the Knowledge Platform on EMF and Health, www.kennisplatform.nl) (Rijksoverheid, 2010). The health advisory body is an independent advisory agency for the Dutch government. The knowledge platform on EMF bundles knowledge on the field of EMF, with its goal to make scientific information available and to explain it. The Dutch government concludes from the information that is provided by the health advisory body and the knowledge platform on EMF, that based on the current scientific literature, one cannot conclude that EMF and health problems are related. Further research should be done, and the results should be evaluated by the health advisory body and the knowledge platform on EMF and health. Furthermore, the Dutch Government refers to the limits of exposure to radio frequency fields from the EU. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is a scientific consultation commission that has defined exposure guidelines, upon which also the EU limits are based. A committee designated by the European commission, the Scientific Committee on Emerging and Newly Identified Health Risks (ec.europa.eu), judged the exposure guidelines of the ICNIRP. The commission concludes that no health effects are demonstrated to be caused by continuous exposure to radio frequency fields below the limits of the ICNIRP. For extremely low frequency fields they conclude that they are possibly carcinogenic. For intermediate and static fields is concluded that not enough data is available. As a reaction to increasing public concern, and to increase knowledge on the topic, the World Health Organisation (www.who.int) started a project to assess the scientific evidence of possible health effects of EMF in the frequency range of 0 to 300 GHz. The project is fully funded by participating countries and agencies. The government emphasizes that there is a lack of information on the effects of EMF, and the EMF product companies adapt to this.

Companies

Mobile phone companies like Ericsson (www.ericsson.com) and Nokia (www.nokia.com) share the opinion that the available scientific evidence does not show any relationship between health problems and EMF. Ericsson provides a brochure on radio waves and health, which covers the exposure limits, health research related to radio waves, electromagnetic safety and exposure to mobile phones and base stations. Both Ericsson and Nokia provide an overview of information of mobile communication and safety issues. Nokia claims to be sensitive to concerns about this topic. KPN (home.kpn.nl) states that the health advisory body does not believe there is a reason to be concerned, but that further research is needed for the long term effects. They also remark that the WHO states that there is not enough scientific evidence to make guidelines for mobile phone use. They state that the proven effects of EMF on health are minimal (Vlijmen, 2003). On the other hand, there are also some companies that sell products that reduce the negative effects of EMF. An example of such a company is Mobichippxd (www.mymobichip.nl). On the website of Mobichip pxd is mentioned that an increasing number of people become aware of the increasing exposure to EMR and the possible negative effects of this radiation for the human body. As a solution, they offer these products. They convince customers that EMR is the cause of the growing incidence of health problems, since several studies already proved that there are reasons to be concerned.

Advocacy groups

There are various advocacy groups that are concerned about EMF. In the Netherlands, there is the Nationaal Platform Stralingsrisico's (National Platform on Radiation risks, www.stralingsrisicos.nl), which commissioned the research project on honeybees and EMF of which this report forms a part. The platform wants to raise more public attention for the health risks of EMF. Next to that they recommend to the industry and the politics that there should be safer devices on the market. The platform aims to contribute to answering questions about the social commotion and health problems that could arise within these fields. They are providing information on how to use the current unsafe techniques. They stress the importance of good scientific research on this topic, in order to force the government to be more careful. Their final aim is to cooperate with national and international organizations to get the environmental factors of EMF on the political agenda. So they are trying to influence the users of EMF products and the policy makers to have a critical view on EMF. StopUMTS (www.stopumts.nl) is another Dutch advocacy group that states there is enough scientific evidence on effects on health from exposure to EMF, so they do not agree with the government and the EMF product companies. They even state that you should not trust the government, because they made mistakes in the past and they do not seem to learn from their mistakes. StopUMTS suggest that EMF has effects on for example the central nervous system, neural activity, blood circulation, functioning of the brains and so on. Although this is not scientifically proven, StopUMTS claims that certain studies suggest that exposure may be harmful on the long term. StopUMTS wants the government to make regulations to guarantee that the human body will not be exposed to higher radiation than 0.1 micro watt per square meter inside, and 1 micro watt per square meter outside houses. At this level they think that there are no health problems caused by the radiation.

2.3 EMF and honeybees

A part of the public discussion focuses on the negative influence of EMF on the natural environment. Several animals and plants are believed to be affected by radiation. Some terms that are often used to refer to adverse effects of man-made EMF in the environment are 'electropollution' or 'electrosmog'. According to Warnke (2009), who's opinion and scientific work is discussed in Chapter 5, mankind is 'destroying nature by electrosmog'. Various internet pages also deal with the subject (e.g. www.hese-project.org, www.stayonthetruth.com, www.emrx.org), which is discussed further in Chapter 5. Very often, bees are mentioned as organisms that will be affected by EMF from communication devices, especially as colony losses in bees have been increasing recently. A part of the public debate on the negative influences of EMF on bees is about the High-frequency Active Auroral Research Project (HAARP) in Alaska (e.g. YouTube, www.abovetopsecret.com, www.newmediaexplorer.org, www.hyperstealth.com). Many conspiracy theories on HAARP circulate (e.g. it is a military weapon that can cause Earthquakes) and it is also suggested to be the cause of colony collapse disorder (CCD). To emphasize the importance of the case of the disappearing bees a quote of Einstein is often referred to. Einstein said, according to several websites, that we will not survive without bees (e.g. Mikkelson and Mikkelson, 2010; www.EMFjournal.com). Honeybees are not only valuable for human life because of honey production, but are very important for crop production. Apart from beekeepers, the problem is therefore also important for farmers. On the internet forum of beekeepers in the Netherlands (www.bijenhouden.nl) one can read that some of the them are concerned about the effects of EMF, but other reactions indicate that most of them do not believe in these effects. The idea that EMF from mobile phones and other communication devices is causing bee colony losses, as well as other possible causes, are discussed in the next chapter.

To summarize the public debate, advocacy groups which believe that there are adverse effects point out to research that suggests this, while companies and policy makers point to studies with contradictory results and claim that there is a lack of scientific proof on negative effects of EMF. The government tries to be objective and stimulates research on EMF and human health, but until there is unambiguous scientific proof, they will not change the policy. On environmental effects much less research has been done, but some sources (e.g. Warnke, 2009; www.emrx.org) claim that our environment is polluted by electrosmog.

3. Uses, biology and colony losses of honeybees

3.1 The use of bees

There are many reasons why bees are important for us, but also for nature. Bees provide useful services, such as pollination. Pollination is done by wild, free-living bees and by selected and commercially managed bee species. The most commonly used bee for pollination is the European honeybee, *A.mellifera* L. (Klein *et al*., 2007). Next to honeybees also stingless bees (for example *Melipona favosa* Fabr.), bumble bees (for example *Bombus terrestris*L.) and solitary bees (for example *Megachile rotundata* F.) are used. Bees are the main, and economically most important group of pollinators in most regions of the world. Pollinators are very important in global crop production, 35% of the crops for production are pollinated (Klein *et al*., 2007). The value of bees for pollination of crops is around 1 billion euro per year in the Netherlands (Blacquière, 2009). Also pollination in nature is very important, especially for biodiversity, as 15% of all wild plant species in Europe are visited by honeybees (Kwak *et al*., 1998). So bees are important pollinators for both natural vegetation and for crops, but bees also make useful products. Bees can make honey, royal jelly, propolis and wax (De Castro, 2001) and collect pollen.

The process of honey making starts when foraging bees collect nectar from flowering plants and take it to the hive. Afterwards the foraging bee forms a droplet of nectar solution, and passes it on to the house bees which store it in their stomach. The house bee manipulates the nectar with her mouthpart to stimulate moisture evaporation (Beespotter, 2010). After this process she regurgitates the nectar solution into a droplet that hangs from her mouth in the air for further evaporation of moisture. At the end she deposits the un-ripened honey into a cell. Worker bees seal the cell with a thin layer of wax once the honey moisture content drops below 20%. Bees use the honey as an energy source, the surplus of honey can be removed from the hive by a beekeeper for human consumption (Beespotter, 2010). In the Netherlands there is no large scale industry for making honey. Currently only hobby bee keepers harvest honey and sell it on small scale to the regional markets (Blacquière, 2009).

Next to honey, bees make wax. Beeswax is the primary nesting material of honeybees (Breed *et al*., 1988). We mainly use beeswax in cosmetic products. Beeswax was already used in ancient times as a cosmetic component, particularly for creams, balsams and cosmetic sticks. In the Netherlands, beeswax is made on small scale and sold to factories who recycle the wax for beekeepers or for example for candle making (Blacquière, 2009).

Another bee product is propolis, an amalgamation of plant resins collected and transformed by bees. Bees use propolis as a glue to block holes and cracks in the hive, to make the border of their nests stronger, and to even out internal walls. People have been using it since ancient times, to disinfect wounds, for tissue regeneration and other therapeutic uses. Nowadays propolis is still used for medicinal uses (De Castro, 2001). In the Netherlands, yielding and using of propolis is only done marginally (Blacquière, 2009).

Royal jelly is used as food for the larvae. All larvae feed on royal jelly, but the future queen gets more than other larvae. Royal jelly is used a lot as alternative medicine, and has several functional properties, such as antibacterial activity, disinfectant action, anti-tumor activity and antioxidant activity (Viuda-Martos*et al*., 2008).

By using pollen traps underneath bee hives beekeepers can collect part of the pollen pellets that the foragers carry when returning to the hive. The collected pollen can be processed to serve as a food supplement to human diets. Unprocessed it is also used as the protein food source for the commercial production of bumblebee colonies for pollination (Velthuis & van Doorn, 2006).

So bees are useful for pollination of crops, but also for making honey, wax, propolis and royal jelly and to collect pollen. Beeswax can be used for cosmetic products, honey for human consumption, propolis for medical uses and royal jelly has several beneficial components which can be used. Pollen can be used for human consumption as well as for the production of bumblebee colonies for pollination.

3.2 General biology of bees

Within the genus *Apis*, eight well-recognized honeybees species have been described (Kevan, 2007). The honeybee belongs to the family Apiidae, in the order Hymenoptera. The *A. cerana*(Asian honeybee) and the *A. mellifera*(European honeybee) are the species that nest in pre-existing cavities (Kevan, 2007). Bees are cold blooded animals, but they keep the hive at ±32 degrees, regardless of the temperature outside. There are three casts of honeybees in the colony: the queen, the drone and the worker (Winston, 1987).

The queen, the drone and the worker all develop through a complete metamorphosis called holometabolism: within three days, the eggs hatch into a voracious larva which molts each day for about four days. Then it goes in a resting stage, the pupa, which stays in a capped cell until it emerges as an adult (Winston, 1987). The total development time is 16 days for a queen, 21 days for a worker and 24 for days for a drone (Page and Peng, 2001).

There is only one queen per hive, and she can lay an average of 1500 eggs per day during spring and summer (Winston, 1987). By secreting a pheromone, the queen keeps the workers uninterested in reproduction on their own. When this pheromone secretion decreases, the workers start to build new queen cells. The queen then lays eggs in these cells, and one of these eggs will become the new queen. The old queen will leave when these larvae pupate, taking one third to half of the population with her to form a new colony (so called swarming) (T. Blacquière, personal communication). Female larvae less than three and a half days old are bipotent. This means that the eggs have the capability to develop either into queen or worker (Page and Peng, 2001). How the egg will develop, depends on the quantity and quality of larval food given by young worker bees called nurse bees (Page and Peng, 2001). The new hatched queen first lets the bees know that there is a new queen by making a beeping sound. The other, still unhatched queens respond with a similar sound from within their cells. The first queen can decide to also leave with a swarm, but if the colony is getting too small she will kill the other young unhatched queens. After she destroyed all her competitors, she takes her mating flights a few days later (Kevan *et al*., 2007).

The number of drones in the hive varies between 0 and a few hundreds. On average, drones live shorter in spring than in summer. The only task of the drone is to mate with the queen, and after mating he will die very quickly (Winston, 1987).

The worker bees are sterile females and their number in the hive bees varies from 10,000 till 50,000. Their life span is much shorter in summer than in winter (Winston, 1987). Three separations can be made regarding the age of workers. Older bees forage for food, water and nest construction. Middle age bees guard the entrance, process food and perform nest construction while the youngest bees feed the larvae and clean the nest.

3.3 Bee colony losses and the possible causes

EMF is often mentioned as one of the causes of large bee losses. It is normal for a beekeeper to lose 10-15% of his bees over winter. Sometimes much bigger losses occur, resulting in an almost empty hive except for some brood (immature bees) and food supplies. These sudden losses are known as 'dwindle disease' and may have many causes. Periods of high losses are not uncommon and have been reported in several periods throughout history (vanEngelsdorp, 2009).

In the last five years, huge losses have been reported, not only over winter but also in other periods (Blacquière *et al., 2009*). It was regarded as a new type of colony loss, despite the absence of clear evidence that it was indeed caused by a new disorder (T. Blacquière, pers. comm.). In absence of an explanation of these losses, the phenomenon was simply called 'colony collapse disorder' (CCD) (vanEngelsdorp *et al.,* 2009). In order to distinguish between CCD and other types of colony losses, an attempt was made to formulate clear characteristics of CCD. VanEngelsdorp *et al.*(2009) defined the following symptoms: “1) the apparent rapid loss of adult worker bees from affected colonies as evidenced by weak or dead colonies with excess brood populations relative to adult bee populations; (2) the noticeable lack of dead worker bees both within and surrounding the hive; (3) the delayed invasion of hive pests (e.g., small hive beetles and wax moths) and kleptoparasitism (stealing of food) by neighboring honeybee colonies” (van Engelsdorp *et al.*, 2009). However, this characterization has also been criticized, because bad beekeeping practices can bias the number of reported incidences of CCD

(T.Blacquière, personal communication). For example, when a beekeeper treats his colony too late against varroa mite, the colony may disappear as a result of bad condition caused by the varroa infection. However, at the time of disappearance, no varroa mites are found in the hive and the loss will be attributed to CCD.

The first dramatic reports of colony losses came from the USA (from 2005 onwards), but since 2000 more countries report sudden losses, affecting to up to 85% of the beekeepers. As mentioned before large losses are not uncommon and can have many more causes than CCD. Many colony losses currently ascribed to CCD may have other causes.

Many possible causes of CCD have been put forward: diseases, pests, pesticides, genetically modified organisms (GMO) farming, electromagnetic radiation, changes in brood temperature, nanotechnology, food deficiencies, and loss of forage. Currently, interactions between some of these factors, especially the pests and pathogens, are regarded as the most likely explanation (Neumann and Carreck, 2010, Oldroyd, 2007, Ratnieks and Carreck, 2010). Electromagnetic radiation caused by mobile phones is thought to have effects on the ability of bees to navigate, causing whole colonies of bees to disappear (Sharma and Kumar, 2010; Warnke, 2009). Also HAARP (high-frequency active auroral research project), a military project with many antennaes based in Alaska, is mentioned as a cause of CCD. In 2006, the antennae of this project were fully used for the first time (Warnke, 2009). In the same year, CCD was reported for the first time (vanEngelsdorp, 2009, Warnke, 2009). However, most research has been focused on other possible causes, such as pathogens.

Drawing general conclusions about causes of CCD has been difficult, because research is being carried out under different circumstances and using different methods. Some of the factors mentioned above have not been studied thoroughly. Moreover, the virulence of pathogens differs in different parts of the world, just as host susceptibility to these pathogens (Neumann and Carreck, 2010, Oldroyd, 2007).

Varroa mite

The varroa mite (*Varroa destructor*) is thought to play a central role in the CCD story, as it exist in almost every colony. Originally, the varroa mite existed only in *Apis cerana*, the Asian honeybee. When the European honeybee was moved to areas where *Apis cerana* lived, the mite switched host. The European honeybee was far more susceptible to varroa, as it had no experience with this parasite (Le Conte *et al.,* 2010). The mite feeds on the hemolyph of the pupa, and later the bee. (bijen@wur). A varroa infection has huge effects on both the bee and the population. Individual bees will lose weight, live shorter, will more likely not return from foraging flights and show impaired learning. When a large fraction of the population is infected, the population will be more susceptible to other (virus) infections. Furthermore, an infected population will produce less brood, and a large proportion of the new brood will be infected as well. This results in an unhealthy winter population, and may cause a crash (bijen@WUR). It is hypothesized that varroa infection causes colony losses. Varroa may interact with other causes, to produce the lethal effect (Neumann and Carreck, 2010). Viruses that would normally be harmless, can cause severe symptoms when bees are infected with the varroa mite or are not in optimal condition because of malnutrition or bad weather (Oldroyd, 2007, Ratnieks and Carreck, 2010). VanEngelsdorp *et al.*(2009) concluded from a large epidemiological study that bees from reported CCD populations had a higher pathogen load than control populations. Moreover, dead and weak colonies from CCD apiaries were more likely to be close together than in control apiaries, suggesting the existence of a common risk factor or an infectious pathogen. However, the conclusions are based on the state of the bees at the moment of collection, and the real circumstances may have been different before sampling (Le Conte *et al.,* 2010).

To conclude, bees are crucial for pollination of many plants, both in the wild and for human purposes. Moreover, most of the products bees make are used by people. The important function of the bee explains why people are so concerned about the inexplicable colony losses. Current research focuses on interactions between the varroa mite and other pathogens. However, if EMF would harm bees, this could also be one of the explanations of colony losses in bees. Especially navigation of bees could be influenced by man-made EMF, as we will explain further in Chapter 4. Other problems in bees that are sometimes claimed to be a result of EMF are problems in learning, reduction of honey production and problems with brood. All these problems could be related to problems in navigation, as bees that can not navigate properly will not be able to produce enough honey. This will in turn lead to less brood. Learning behaviour could be impaired when bees have problems with navigation at the first time they fly out to learn to know the surroundings of the hive. In the next chapter, we will discuss possible ways in which bees could be harmed by EMF in more detail.

4. How could honeybees be affected by electromagnetic radiation?

In the previous two chapters we have discussed EMF and honeybees, respectively. It was discussed that there are many concerns on EMF, including the suggestion that EMF might be harmful for bees and that it might be a cause of colony loss. In this chapter we further explore the possibility of EMF being harmful to bees. First, we will look into the available literature on studies of EMF effects on other organisms, to see if that might provide clues for possible effects in bees. Studies on *Drosophila*, rats, birds and plants are discussed. After that, the suggestion that bees might be hampered in their orientation or navigation is further investigated. An overview is given of how bees use different cues for navigation: the sun, polarized light, landmarks and magnetoreception with both magnetite and cryptochrome receptors. At the end of each section we will present some conclusions.

4.1 Effects of EMF on other organisms

A lot of studies have been done on the effects of EMF on mammals, insects and some on plants as well. In this paragraph, an overview of these studies will be given. Studies on the effects of EMF on the fruit fly (*Drosophila melanogaster*) will be highlighted as this species is relatively closely related to the honeybee (both are holometabolous insects). Studies about the effects of EMF on orientation will also be discussed in this paragraph, as honeybees and other animals which make use of a magnetic compass have a similar mechanism for navigation.

Studies on animals confirmed that the most consistent and reproducible responses to acute radio frequency (RF) exposure were caused by thermal effects (Vecchia *et al*., 2009). When animals' core temperatures are increased by about 1 °C due to thermal RF exposure, deficits in learning behaviour occur. A significant increase in body temperature caused by RF radiation can impair male fertility and increase incidences of foetal malformations and anomalies as well as embryo and foetal losses (Vecchia *et al*., 2009).

Effects of EMF on the nervous system of both animals and humans have been shown by laboratory studies. It has been suggested that long-term (more than ten years) mobile phone use increases the risk of certain cancer types (acoustic neuroma and glioma) (Hardell and Sage, 2008). However, carcinogenic effects on rodents are not likely to occur at SAR levels below 4 W/ kg (Vecchia *et al*., 2009). Experiments on rats (Kumlin *et al*., 2007; Vecchia *et al*., 2009) indicated no serious threat to the developing brain from mobile phone radiation at intensities similar to human exposure. However, those experiments showed that mobile phone radiation can affect memory and learning behaviour.

Drosophila

GSM 900 MHz and DCS 1800 MHz radiation of mobile phones was used to study the effect of telephony on the reproductive capacity of *Drosophila*. It was shown that the radiation caused fragmentation of DNA in the gonads, which caused a decrease in the insect's reproductive capacity with 50-60% (Panagopoulos *et al*., 2004).

In contrast to the study of Panagopoulos *et al*., exposure to GSM mobile phones (900/1, 900 MHz; SAR ~ 1,4 W/kg) resulted in a greater number of adults in *Drosophila*, from 22% to 50% higher, depending on the proportion of males in the experiments (Weisbrot *et al*., 2003). *Drosophila* salivary gland chromosomes exposed to electromagnetic fields showed an increase in the transcriptional activity in 73 of the 200 investigated chromosomal regions (Goodman *et al*., 1992a, b) including housekeeping genes. This could be a reason for the increased number of offspring. The study of Weisbrot also showed that cell phone radiation increases the level of heat shock protein 70 (hsp70, a stress factor), which suppresses apoptosis (Beere *et al*., 2000). Furthermore, in larvae of *Drosophila* an influence on the regulation of the MAPK cascade was found, which controls the expression of specific genes that control cell proliferation, metabolism, cell survival in case of injury or infection and other major organismal processes (Weisbrot *et al*., 2003). This pathway is not stimulated by heat, so the authors conclude that non-thermal effects play a role here. However, thermal effects might have also occurred in these studies, as the radiation source (the mobile phone) was placed very close to the animals. These studies show effects in cellular functioning and could be highly relevant to the situation in bees. *Drosophila* and the honeybee are both holometabolous insects so they share similar developmental processes. Therefore, we think it is very well possible that these effects could also be found in bee larvae.

Birds

There are in total 47 species, including honeybees, that make use of a magnetic compass (Wiltschko and Wiltschko, 2005). Of these 47 species, 20 are bird species (Wiltschko and Wiltschko, 2005). *Passer domesticus* (house sparrow) and *Ciconia ciconia* (white stork) are two of these 20 bird species on which research has been done. A preliminary research showed that fewer house sparrow males were seen at locations with relatively high electric field strength values of GSM base stations in a range of 900-1800 MHz (Everaert and Bauwens, 2007). However, the sample size of this study was very small due to the very short observation time (5 min) at each location. Another study showed that under influence of electromagnetic radiation of a relatively high intensity (2,36 ± 0.82 V/m), a significantly lower number of white storks fledglings (young birds) were observed in nests, compared with nests receiving lower levels of radiation (0.53 ± 0.82 V/m) (Balmori *et al*., 2005). In addition, bird species which use magnetic navigation can become disoriented when exposed to weak (less than a tenth of Earth magnetic field strength) high frequency magnetic fields (Thalau *et al*., 2005). These studies (Balmori *et al*., 2005; Thalau *et al*., 2005) seem reliable with sufficient sample size, clear material and methods and significant results.

At the moment, a research project on the effects of EMF on chicken embryos is being conducted by the Animal Sciences Group of Wageningen UR. In the experimental set-up they are investigating hatching rate and morphology/histology of hatched chicken as well as gene expression and morphology/histology at three embryonic stages. Preliminary results show some effects, but this is on the verge of being statistically relevant (Hugo Hoofwijk, pers. comm.)

So in studies on birds, which share similar navigational means with bees, negative effects have been found. The study on the decline of sparrows was unfortunately not very reliable, so it does not provide clues on EMF as a possible cause of declines in certain species. But, as navigation in birds seems to be affected, this could also hold true for the bees. In Paragraph 4.2 we focus more on the mechanism of navigation in bees.

Plants

In a study on young spruce (*Picea abies* (L.) Karst.) and beech (*Fagus sylvatica* L.) trees with similar radiation (microwave) as for the ash-study, hardly any significant effects were found after an exposure period of three years (Schmutz, *et al*., 1996). What was found were lower calcium and sulfur concentrations in the leaves of Beech trees in the first two years, but not below sufficiency levels. The effect was absent in the third year of exposure. Tafforeau *et al*. (2006) found changes in the proteome (the protein composition of cells) after GSM exposure in *Arabidopsis* seedlings. In flax (*Linum* sp.) seedlings, they only found an effect in combination with calcium depletion. The study shows that plants react to EMF as an environmental stimulus, so it does have an effect on plants. But, the study does not show harmful effects. Vian *et al*. (2006), however, found that a certain transcription factor (*LebZIP1*) that is associated with stress-responses in plants, was produced at a higher rate after exposure to GSM signals in tomato plants (*Solanum lycopersicum* L.). Because of the low intensity of the radiation in their experiments, they conclude that this is caused by non-thermal effects. The response to the EMF is reproducible and is absent in plants that were shielded. To summarize, there seems to be some evidence for (adverse) effects of EMF in plants, although other studies did not find significant effects.

In vitro studies

In Vecchia *et al*. (2009), an overview is given of *in vitro* studies that investigate possible effects at the cellular level. The main findings are summarized here. Most *in vitro* studies show no thermal effects of radio frequency (RF) exposure towards cell proliferation and differentiation, apoptosis and cell transformation. Because of the inconsistency of the *in vitro* studies on the non-thermal effects of RF radiation on calcium physiology and because of the inconsistencies and methodological limitation of *in vitro* studies on non-thermal RF radiation exposure to gene/protein expression (including stress protein expression and cancer related genes), final conclusions about these topics cannot be made. Furthermore, most studies on genotoxicity show that there is no *in vitro* genetic damage under influence of RF radiation. However, a large part of these studies focuses on gross structural abnormalities and therefore fine indirect effects could not be seen. Vecchia *et al*. (2009) conclude that no consistent evidence of biological effects under non-thermal radio frequency (RF) exposure conditions has been provided so far by *in vitro* studies (Vecchia *et al*., 2009). In addition, the effect of electromagnetic fields at the cellular level depends on many factors like the organism (*in vivo*) or cell line (*in vitro*) being studied, the exposure time and the type of exposure. Therefore these *in vitro* studies do not provide many clues for effects at the cellular level in honeybees.

To conclude, thermal effects of EMF on animals can cause a deficit in learning behaviour and reproduction. In *Drosophila,* reproduction can be influenced by EMF, but this may be mostly caused by thermal effects. That could be expected to also be the case for honeybees. However, thermal effects of EMF seem not be relevant because in nature, honeybees are usually not expected to be exposed to electromagnetic radiation with field strengths high enough to cause thermal effects. EMF seems to be able to influence the orientation of birds, which is an important conclusion as birds seem to use the same mechanism for orientation as honeybees. Studies on the influence of EMF on plants show that there might be an effect. In general, there is scientific evidence for EMF effects in living organisms. However, many studies are contradictory so firm conclusions cannot be drawn. But the results of studies on other organisms also show that adverse effects on living organisms cannot be ruled out, so research on adverse effects of EMF on honeybees seems to be worthwhile.

4.2 Could the way bees navigate be affected?

As discussed below, the sun's position is thought to be the most important cue that honeybees use for navigation. It is not expected that EMF could have an effect on that. However, bees also use other mechanisms for navigation. In fact, animals have multiple compass systems which help them to navigate like the sun, stars, polarized light and magnetic compasses (Wiltschko and Wiltschko, 1972; Emlen, 1975; Schmidt-Koenig, 1979; Phillips, 1986b; Moore, 1987; Wiltschko and Wiltschko, 1995a; Lohmann and Lohmann, 1996). Which compass system will be used depends on weather conditions, time of day and past experience. For each of these compasses, different sensory detection mechanisms are required, e.g., cryptochrome for polarized light (Phillips and Waldvogel, 1988; Schmidt-Koenig, 1990). In birds, where the integration of compass information is best understood, the primary compass calibration reference appears to be derived from celestial cues, probably polarized patterns present at sunset and, possibly also sunrise (Phillips *et al*., 2006). Magneto reception in animals has been a very controversial topic, although already since the seventies a lot of experimental work has been done (Kirschvink, 2001). That honeybees can sense magnetic fields has been known for quite a while (Gould and Gould, 1988), but it was not thought to play an important role in their navigation, until recently. Recent studies shed more light on the mechanisms of magneto reception (Kirschvink *et al*., 2001; Hsu *et al*., 2007; Winklhofer, 2010; Liedvogel and Mouritsen, 2010). If magneto reception is important in honeybee navigation, EMF might have an influence, as is discussed in the following paragraphs .

4.2.1 Navigation by the sun's position, polarized light and landmarks

The most important cue for bee navigation is thought to be the sun's position, which changes during the day from sunrise at East to sunset at West. At dawn and dusk, the sun is moving rapidly and vertically in the sky, therefore dawn and dusk are the easiest cues for bees to estimate their location, in contradiction to noon when the sun is at azimuth (Gould and Gould, 1988). Bees use an average value for the sun's westward movement; the mean rate is 15 degrees per hour (Gould and Gould, 1988). When a forager comes back from a good food source, she indicates its position to others with the waggle dance. The waggle dance is based on orientation towards the sun. For example when the dance is performed pointing to the upper part of the hive, it means that the source of nutrients is exactly in the direction of the sun. If the waggle is pointing downwards, it means that the food source is at the opposite direction of the sun. The numbers of waggle vibrations gives the distance of the food source (Gould and Gould, 1988).

Orientation by polarized light

When the sun is not visible, for example inside dense forests or under heavy cloud cover, bees use polarized light for orientation. Polarization refers to the way light waves vibrate as they travel through the sky. Light coming from the sun is scattered by the air molecules in the atmosphere. As seen from the bee, the light will be polarized perpendicular to the line between the bee and the sun. This results in a pattern where the sun is encircled by polarized light. The intensity of polarization changes as it is farther away from the line perpendicular to the sunlight's direction; the greater the difference from the optimum of 90°, the less intense the polarization (Gould and Gould, 1988). Bees use these patterns and differences in polarization intensity to navigate, although it is not clear how they do this. The main problem with using polarized light is that it is impossible to know the exact location of the sun. When looking at polarization intensity and pattern, it is possible to determine a line where the sun should be. There are several methods to determine the exact location of the sun, but which one the bees use is unclear (Gould and Gould, 1988).

However, it seems that all the methods to exactly determine the sun's position that bees use result in some systematic errors, and all options foresee problems with navigation at noon, a time where most bees are inactive (Gruter and Farina, 2009). Bees are able to see the sun through UV and blue light. Studies show that in environments with UV, bees are more active which is related to the presence of cryptochrome, also involved in magneto reception in insects (Costa and Robb, 1999; Morandin *et al*., 2001; Costa *et al*., 2002).It is possible that bees might not forage as efficiently in environments without UV (Morandin *et al*., 2001). However, when UV is totally excluded from the foraging environment the ability of bumblebees to use their visual system to find flowers was found not to be adversely affected (Dyer and Chittka, 2004). But the experimental set-up of that study was not very suitable, the maximum distance that the bumblebees would have to fly was 1.5 m. So the bumblebees could just walk towards the flowers on smell.

Landmarks

Landmarks also play a role in bee orientation. However, a bee does not have very detailed vision so only very close or large landmarks can be used. Even a quite distinct landmark such as a tree can only be seen by a bee from a few meters distance. Therefore, other orientation mechanisms play a much bigger role (Gould and Gould, 1988).

The sun's position, polarized light and landmarks are the best understood ways used by bees for navigation but it seems unlikely that these mechanisms can be affected by EMF. Magneto reception, another way of orientation, is will be discussed in the next section. This might provide more clues if bee navigation can be affected by EMF.

4.2.2. Navigation by magneto reception

Magnetoreception refers to the way organisms can perceive natural magnetic fields (like the Earth magnetic field and use them for different purposes like orientation. In bees, magnetoreception is thought to act through magnetite and cryptochromes. Different authors have also mentioned a relation between natural magnetic fields and UV-light perception in orientation mechanisms of animals (Edmonds, 1996; Wiltschko *et al*., 2009; Winklhofer and Kirschvink, 2009; Gegear *et al*., 2010; Phillips *et al*., 2010; Winklhofer, 2010).

Earth magnetic field

The Earth magnetic field (and the surface magnetic field) is approximately a magnetic dipole, with the magnetic field south pole near the Earth's geographic North pole and *vice versa* (see Figure 3.1). We usually use a compass to determine which way is north, which is made possible by the Earth magnetic field. The lines of the magnetic field begin at the North pole region and end at the South pole region. Its axis is almost the same as the rotation axis of the Earth. It continuously changes over time. That is why a compass merely points to North which implies the need of different compass systems for accurate navigation (Pople, 2007).

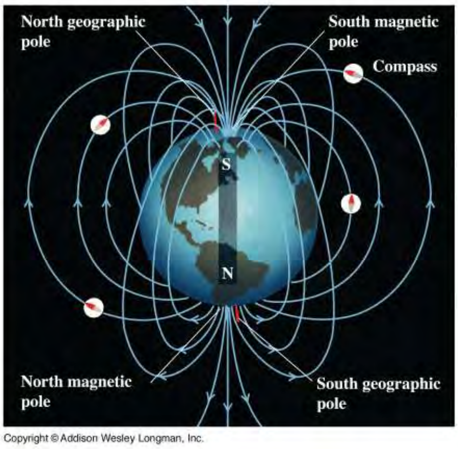


Figure 2. Earth magnetic field.

The strength of the field at the Earth's surface ranges from less than 30 microTeslas (µT) in an area including most of South America and South Africa to over 60 µT around the magnetic poles in northern Canada and south of Australia, and in part of Siberia (Pople, 2007). Bees sense the Earth magnetic field, and use this field to determine the direction in which new honeycombs should be build in the dark in nesting cavities (Gould and Gould, 1988). This magneto reception system is highly sensitive, because honey bees can detect magnetic fields as low as 26 nanoTesla (nT), compared to the 45000 nT of Earth's magnetic field (Kirschvink *et al*.,1997).

Magnetite

Bees are able to sense magnetic fields by (super)magnetite, located in iron granulates in their abdomen. These granulates change in size as a reaction to changing magnetic fields. The size change leads to relaxing and tensing of the cytoskeleton in trophocytes, which in turn leads to signal transduction for magneto reception. In this way, honeybees are able to make a magnetic map during orientation flights (Hsu *et al.,* 1997). Winklhofer and Kirschvink (2009) focus their studies on the torque-transductor (torque: rotation force around a pivot or axis) model in order to understand how the perception of magnetic field through ferromagnetic material in animal bodies is transduced into nerve signals. In the same study two theories are presented, the first one says that the "magnet is coupled" to a mechanosensory system that converts the force into a torque. The second theory explains the movement by intracellular magnets that align with the magnetic field. Finally, the study explains the rotation forces indicating that, as a first step, cells are aligned to a strong field to determine the orientation. Later, the rotation is done in the optical plane. The responses are determined by the grade in which the magnet is anchored in the cell and are also depending on the sensitivity of the mechanism to the polarity or the magnitude of the field.

Cryptochrome

The first hypothesis about magneto reception shows magnetite as the primary agent of Earth magnetic field detection; however other theories as the radical-pairs (Ritz *et al*., 2000) gain more popularity. This hypothesis states that cryptochrome (cry) proteins in the retina of certain animals, as honeybees and *Drosophila* (Gegear *et al*., 2010; Wajnberg, 2010; Winklhofer, 2010), are responsible for the magneto reception in the inclination of compass information (Winklhofer, 2010). Cry contains pigments that under short wavelength light may form a spin-correlated radical pair that is dependent on the strength and axial orientation of the external magnetic field to define the grade of the reaction (Winklhofer, 2010). In other words, the short wavelength light may initiate a chemical reaction (radical pairs) that starts in specialized photoreceptors. The specialized receptors are the cryptochromes that generate magnetically sensitive radical pair products; however, it is not yet precisely clear how the magneto sensitive chemical reactions are converted into neural signals (Gegear *et al*., 2010).

Bees response to light and magnetic fields

Research has shown that among animals, magneto reception differs and is as well localized in different parts of the body (Edmonds, 1996; Winklhofer and Kirschvink, 2009; Gegear *et al*., 2010; Phillips *et al*., 2010). Wajnberg *et al*. (2010) has particularly focused on eusocial insects as bees. They explain that animals can have a compass that senses magnetic polarity (north-south) or the inclination compass (equator ward directions). The inclination compasses are light dependent while the polarity compasses are independent of light conditions. The latter is therefore the most likely system for deciding on honeycomb building direction in the dark in nesting cavities. The study shows how honeybees' orientation is affected by changes in magnetic field intensity and polarity as well as by changes in the wavelength of light. Regarding the light-dependent magneto reception, the study suggests that incident light is only detectable when the animal is parallel or antiparallel to the direction of the Earth magnetic field and the perception is possible though particles in the eye that anisotropically (directionally dependent) absorb light. In relation with the ferromagnetic hypothesis (torque-transductor) it is thought that supermagnetic (SPM) crystals collectively interact with the Earth magnetic field allowing thermal fluctuations that produce stress in the animal and help to transduce the information in the nervous system. In this sense the torque helps to "balance the thermal energy at room temperature" (Wajnberg *et al*., 2010). In honeybees it was observed that magenetite (Hsu *et al*., 2007) can "shrink when parallel to the magnetic field and enlarge at the vertical direction in the horizontal plane" (Wajnberg *et al*., 2010). The magnetite is proposed to be located in the dorsal hairs of honeybees' abdomens and the antennae where SPM has been found. It is thought that electromagnetic fields can act on the dendrites and the signal is amplified by the hairs, as a result generating a stimulus in the nerve. The studies in eusocial animals suggests that magnetic orientation in bumblebees is light independent while those related with the waggle dance and homing are light sensitive, but not dependent (Edmonds, 1996; Wiltschko *et al*., 2009; Gegear *et al*., 2010; Phillips *et al*., 2010; Wajnberg *et al*., 2010; Winklhofer, 2010; Winklhofer and Kirschvink 2010).

In conclusion, honeybees, like other animals, use the Earth magnetic fields for navigation purposes as is shown by different authors. In case man-made EMF disturbs the way honeybees sense the Earth magnetic field, they could be affected in their homing ability and/or the accuracy of the waggle dance. However, they could in many situations perhaps still rely fully on other navigation systems, like the sun's position. There are still clear knowledge gaps in the theories of magneto reception and its importance for bee navigation. Studies on the influences of artificial EMF could provide helpful clues for the importance of magneto reception next to investigating possible harmful effects on honeybees.

5. Literature evaluation

In this chapter we review the scientific literature that is available on effects of EMF on honeybees. Next to that we shortly discuss a couple of websites (paragraph 5.4) that deal with the topic and often claim to use reliable information from scientific studies. We will first discuss some literature on the effects of high power electrical transmission lines in paragraph 5.1. After that some studies on effects of induced magnetic fields on the waggle dance will be dealt with in paragraph 5.2. There are not many articles from scientific journals on the effects of radiation from mobile phones or other communication technologies on honeybees, but in paragraph 5.3 we discuss several articles from research groups of the university of Koblenz-Landau, a review on the topic that was published as a brochure and a study that was done by two Indian researchers.

Quality assessment

As described in the introduction, we determined the reliability of information about the effects of EMF on bees. We studied the documents thoroughly and discussed several points together. A list of guidelines that we used as criteria for our assessment is included in Appendix 1. On the basis of these points, we decided if the information is reliable.

5.1 Transmission lines (extremely low frequency fields)

> Greenberg, Bindokas and Gauer
>
> - Effect of ELF from high tension power lines on bees
> - Effects are local and are an in-hive phenomenon
>   - Reliable articles

The article of Greenberg *et al*. (1981) and the articles of Bindokas *et al*. (1988a, 1988b and 1989) focus on exposure of honeybees to extremely low frequency (ELF, 60 Hz) radiation from transmission lines of 765-KV (exposure range was from 0.65 KV/m, 8.5 µA to 7 KV/m, 100 µA). Greenberg *et al*. (1981) found dose-related responses in foraging activity, net weight of the honeycombs and queen losses. From this it can be concluded that the effects of electric fields of transmission lines are local and that the effects are an in-hive phenomenon (hives shielded with protective mesh (Faraday) below the transmission line did not show any response). At distances of 16.3 m and closer to the transmission lines, clear harmful effects were found, while beyond 29.2 m from the transmission lines, no effects were found. Bindokas *et al*. (1988a, 1988b, 1989) show that the effects are mainly due to electric shock, caused by the EMF. The occurrence of electric shock depends on the conductivity within the hive, which is for example influenced by the presence of moisture. This was studied by placing a tunnel at the entrance of the hives, in which electric currents were generated (Bindokas *et al*., 1988a and 1988b). In laboratory experiments with live and freshly killed bees, it

became apparent that electric shock results in changes in behaviour: the bees, when placed on a conductive substrate, showed stinging responses and decreased motor activity at >200 and >300 kV/m, respectively (Bindokas *et al.*, 1989). Wings of dead bees were vibrating under electric currents of >150 kV/m, but this was thought not to be important for the adverse effects in exposed colonies, as live bees showed no differences in behaviour below 200 kV/m.
An earlier study by Wellenstein (1974) in Germany under 100 kV resulted in an increased honey harvest in a nice summer, but under 200 kV in a wet summer the bees became very irritable and most colonies started to swarm. This study was peer reviewed, but conducted with small groups of colonies, and no information about statistics was given.

All the articles above (Greenberg *et al*. 1981 and Bindokas *et al*. 1988a, 1988b and 1989) were published in the Bioelectromagnetics journal. The journal is specialized in biological effects and applications of EMF and is peer-reviewed. The Bioelectromagnetics Society sponsors the journal (Bioelectromagnetic society, 2010). The authors are connected to the company Bioconcern and for the department of Biological Sciences on the University of Illinois and the electronics division of the IIT research institute in Chicago, so their field of study does seem to be directly related to the topic. The aims of the articles and purpose of the research are clear. They have used appropriate methods and a clear figure is shown about the research lay-out. Many hives (in total 48) were used and they were selected randomly. Observations were done independently, two persons counted and observational differences between these persons were taken into account. They have used proper statistical analyses and the results are clear and detailed. The discussion is elaborated and they have also criticized their own results. The conclusion from the article is clear. One point: they do not use many references, and the references they use are mostly from their own previous research. We conclude that the results from these studies are reliable and that honeybees will be adversely influenced by high power transmission lines when beehives are placed close to those lines. Lipinski (2006) states in a short review that bee hives should be located at least 65 meters from an electric power line of 75 k V tension.

5.2 Effects of magnetic fields on the waggle dance

Korall *et al*., 1988 & Martin *et al*., 1988

- Effects magnetic fields on waggle dance
- Jumps of misdirection in the waggle dance and decrease in dance tempo
  - Reliable articles

The waggle dance is the way for worker bees to communicate the position of food sources and is dependent on the way in which they navigate. So in case magnetic sense is important in bee navigation, effects of EMF on the waggle dance could be expected. Korall *et al*. (1988) studied the effects of magnetic field bursts and found jumps of misdirection of up to 10° as became evident from the waggle dance of foragers. In previous studies (Lindauer and Martin, 1968; Martin and Lindauer, 1973 and 1977; Lindauer, 1976) it was already found that variations during the day in the Earth magnetic field, as well as induced magnetic fields, could lead to misdirection of the waggle dance. By applying bursts of EMF (250 Hz) parallel to the Earth magnetic field, misdirection in the waggle dance is increased compared to the daily pattern. Martin *et al*. (1988) focus on the effect of artificial magnetic fields on flying activity, life span and dance tempo of honeybees. The flying activity and life span of the bees was determined under Earth magnetic field conditions and a static artificial inhomogeneous magnetic field (5 Hz), in indoor experiments under continuous feeding. The flying activity was found to be lower under inhomogeneous field conditions as compared to Earth magnetic field conditions by 40%, measured as the number of visits to the feeding place. Consequently, because it is dependent on activity, the life span of worker bees was found to be prolonged by 60-74%. The dance tempo of the bee was determined under Earth magnetic field conditions, compensated magnetic field conditions (2% of the Earth magnetic field) with or without a simultaneous application of magnetic fields in the range of 5 Hz to 770 Hz. A significant decrease in dance tempo was found under Earth magnetic field conditions, compensated Earth magnetic field conditions and 2-fold amplification of the Earth magnetic field conditions. By applying of 5-770 Hz (with the exception of 250 Hz) the bees slow down their dance tempo and with this they inform their nest mates about a wrong feeding place that is far more than 600 m away from the hive, while the true distance to the feeding place was 415 m. An interesting point to mention here is that at 770 Hz, the effect is lower than at 15 or 5 Hz. It is unknown if and how these frequencies compare to higher frequencies (like those generated by mobile phones or WiFi).

The overall quality of these articles could be judged as acceptable. The background of the authors seems fitting (Zoology department of the University of Würzburg). The article is published in the Journal of Comparative Physiology, and it is peer-reviewed. The number of observations for each experiment seem to be high enough. Some flaws for the studies by Martin *et al*. (1988) were found however. The purpose of the article is not clearly stated in the introduction. The material and methods section is seriously flawed, the way in which observations were made is not clearly explained and they seem to have forgotten to mention certain aspects. For example, they mention in the results the influence of magnetic fields of 5-770 Hz on the dance tempo but they only mentioned artificially induced fields of 5 Hz in the material and methods section. The same goes for the 2-fold amplification of the Earth magnetic field, it was not mentioned. They are also not consequent in using the statistical methods, no standard deviation or number of observations is mentioned for the effect of a static homogeneous amplified magnetic field on flying activity. These flaws in the material and methods section cast some doubt on the trustfulness of the results.

The studies on the influence of EMF on the waggle dance show that bursts of EMF (250 Hz) can lead to misdirection in the waggle dance and that compensation of the Earth magnetic field or artificial (5 and to a lesser extent 15-770 Hz) can decrease dance tempo. We think that these conclusions are quite reliable, but we would recommend further research on the effects of EMF on the waggle dance (see also Chapter 6).

5.3 The effects of high-frequency EMF

Scientific studies on the effects of wireless communication technologies as mobile phones, DECT-phones and WiFi on honeybees, is what we were most interested in. Unfortunately, there are very few studies that have been published in scientific journals. The publications that are discussed here are mostly not peer-reviewed and are not from high quality international journals. Whether these publications hold any reliable information is discussed in this paragraph.

The work of Stever, Kuhn and co-workers

Prof. H. Stever and Dr. J. Kuhn, both from the University of Koblenz-Landau, have cooperated for a number of studies on effects of EMF on honeybees. They have published some of their results together with their co-workers (Stever and Kuhn, 2003; Harst *et al*., 2006; Kimmel *et al*. 2007). Their work involves a model to study learning behaviour in honeybees (Stever and Kuhn, 2003). They first tested it in an explorative study, with a base station for DECT-phones (1900 Mhz, average transmitting power of 2.5 mW with a peak of 250 mW) placed inside the beehive. They did not find any changes in behaviour in the first explorative study (Stever and Kuhn, 2003). In a later study (Harst *et al*., 2006), they investigated the returning behaviour and honeycomb weight and area with the same experimental set-up. They found that fewer bees returned when a DECT-station was placed inside the hive, and that they generally took a longer time to return. The honeycomb weight was also lower for exposed beehives (1045 g opposed to 1326 g in non-exposed colonies, starting weight was similar in both, approximately 700 g).

> Stever, Kuhn, Harst, Kimmel
>
> - Effect of EMF from DECT phones on learning behavior of bees
> - Fewer bees returned; It took a longer time to return; Lower honeycomb weight
>   - Unreliable articles

From the previous work done by the authors you would expect that the quality of the articles would be high, however, in the publication of Harst *et al*. (2006), the experimental set-up was flawed in many aspects. First of all, the introduction of the article deals with learning behaviour and no suitable hypothesis that can be tested with the experimental set-up is given. Moreover, the introduction apparently mainly builds on their own work (which seems rather vague, e.g. the "super signs" theory is not supported by any other reference than their own (Stever, 2002) and no further information was found on that theory). Furthermore, the article as well as their scientific background (educational informatics and physics) do not testify that they have any sound knowledge on honeybee biology, although they did many studies on bees, they are in the department of educational informatics and physics. It makes one wonder if the writing of the article is perhaps also the work of the students that they say have conducted the experiments.

The experimental set-up is inappropriate, because only 4 exposed and 4 non-exposed colonies were used, which seems too few to do proper statistical analyses on. They did a Mann-Whitney U-Test and did not find a difference in honeycomb area between exposed and non-exposed colonies. For the other measurements, they do not report any statistical analyses. Furthermore, placing an EMF source inside the beehive might cause effects on the bees that are not related to radiation, e.g. the bees might be repelled by the smell or the sound of the machine. The control group had no dummy DECT-station and nothing to compensate for other effects from the stations than the radiation. DECT-phones are mostly used inside buildings, therefore their experimental set-up also does not represent a natural situation. The EMF source is placed so close to the bees that the exposure level of EMF is far greater than can be expected in natural situations, and in this situation thermal effects can also not be ruled out. It is also highly questionable in our opinion that this is a proper experiment to study learning behaviour, because what is measured is dependent on many different environmental variables. If effects of EMF could be found in returning behaviour or honeycomb size/weight, that does not provide any direct clues on whether learning behaviour is affected.

The observations were made manually and if a blind/double blind approach is used is not mentioned. They installed bee scan units on the hives, to automatically register the returning behaviour of the bees, but the data were incomplete because of technical problems. Weather data was also incomplete. In the end, they also do not draw any conclusions, they just show the results and suggest improvements for further studies. A study like this that has serious flaws and incomplete data should not be published at all in our opinion.

A second article on honeybee experiments was published, with pretty much the same experimental set-up (Kimmel *et al.*, 2007). The introduction of this article is somewhat better than the previous one and they provide some references other than their own. There is again no clear link between the introduction and the rest of the paper. This time around they do use more hives, distributed over three experimental groups: with 100% radiation (5 hives), with 50% radiation (3 hives), and a control group (without radiation, 8 hives). They still do not place a dummy DECT-station in the non-exposed hives. In the 50%-radiation group, DECT-stations were shielded by cubic shields made of reed and clay. A serious incompleteness here is that they did not measure the intensity of the radiation in the different groups. The reported 50% reduction in radiation by reed and clay is only supported by a reference (Moldan and Pauli, 2000), which cannot be traced back. The hives of different groups are separated by metal lattices. However, this will only have an effect of radiation inside the hive, not the surrounding area. All the hives are placed next to each other. They still use the same observation time of 45 minutes. They use 15 bees per test run per hive. In the results, they do not find significant differences between returning percentages in the different treatments. It looks like they are trying to find significant results by changing variables, because they introduce a new term, the *tn*-index. The term is a combination between returning time and returning percentage. Using this term a significant difference is found between the 100%-radiation group and the control group. Calculation of the *tn*-index is not simple: the number of returning bees is multiplied by the maximum observation time (45 min) plus 1 (which they do not explain), then the summed returning times of all bees are subtracted and finally the term is standardized by relating it to the maximum value. This

renders the index uninformative. In the graph of *tn*-indices, all the comparisons of pairs between the 100%-exposed and the control group are shown, and for only about one third of them, a clear difference can be seen. In the discussion, the authors are critical of their own experiments to some extent. In fact they say that many factors in the experimental set-up are hard to control, but that at least location, homogeneity and interactions with non-studied colonies should be "observed and controlled before starting a following study". If they did not do that for this study in the first place, it makes the research all the more questionable. But they also conclude that their results do not prove a possible influence of the radiation. The difference between 100%-radiated and control groups is according to them due to an influence of high-frequency radiation. In our opinion, they could only conclude this by misusing statistical methods to show significant differences. They end the article with a smart comment: "it would be very important to measure the exact radiation intensity within the hives".
The latter two articles (Harst *et al*., 2006 and Kimmel *et al*., 2007) were published in 'ActaSystemica', the journal of the International Institute for Advanced Studies in Systems Research and Cybernetics (IIAS). The journal is not traceable, it is not published online. It seems that the journal does not have a peer-review system and it is not indexed in any of the well-known scientific literature databases (e.g. Scopus). Apparently, Stever and Kuhn received an award for their innovative research from the IIAS and are now affiliated to that organization (H.e.s.e.-project, 2010b). This seems quite peculiar. Also quite remarkable is that one can hardly find any other literature dealing with the models and theories that these two researchers are working on. In any case, their work on honeybees and EMF is of low quality and it provides hardly any reliable information.

Warnke (2009)

Dr. rer. nat. Ulrich Warnke has been working on the topic of EMF for decades, and his work has received more attention in the last years. Many websites on health and environmental risks of EMF do refer to his work as a reliable scientific source. He recently wrote a brochure (Warnke, 2009) for the German advocacy group Kompetenzinitiatieve (Competence Initiative, "for the protection of humanity, environment and democracy" against EMR) .

Warnke, 2009

- Review on adverse effects of EMF
- Bees disappear due to EMF
    - Unreliable article

The brochure can be seen as a review on the adverse effects of EMF, focussing mainly on humans, bees and birds. It explains that magnetic fields influence animals in their navigation system. It is statedthat magnetite is present in bees, which is used to sense the Earth magnetic field. It is considered to be the primary mechanism of navigation, in contrary to what is stated by most honeybee researchers. The paper explains how bees orientate using polarized light, air pressure, gravity and aromatic molecules. It is affirmed with certainty that the bird navigation system is extremely sensitive to weather, but no reference is given. To explain his theory the author describes how electromagnetic impulses affect animals, quoting his own work.

Afterwards it is explained how the air is electrically charged and how this interacts with the flying of the bee. The author claims that also the bees are electrically charged as well as the beehive which determines the total electrical charge of the colony. Successively, the effect of artificial fields on bees is discussed, it is stated that fields of 50Hz makes bees restless and sting one another to death. It is also explained how the waggle dance of bees generates electrical signals. At the end, according to the report the full activation of the High Frequency Active Auroral Research Project (HAARP) and colony collapse disorder (CCD) are related. Also is a link mentioned with the lack of nitric oxide (NO) molecules which is damaging the olfactory orientation and immune system of bees, explaining why bees have become so sensitive to viruses, bacteria and other infectious agents, all due to "electro smog".
This review by Warnke is mainly based on his own work, and many of the other references are personal communication, unpublished work or even TV programs which are not reliable sources. He exaggerates a lot and many of his theories are not in line with the generally accepted views of the scientific community that is working on honeybees. He did not link his idea properly which makes his theory difficult to understand. He used Harst *et al*. (2006), which was found unreliable, to emphasize the harmful effects of artificial electromagnetic fields on honeybees. Moreover, he shows a figure from Gould and Gould (1988) that he edited and claims copyright for it. Thus Warnke's review was judged by us to be highly unreliable and the author to be strongly biased.

Sharma and Kumar (2010)

A recent study by Sharma and Kumar (2010) received quite some attention in the media, but was heavily criticized by the scientific community working on honeybees. Their article describes experiments that were conducted in India on the influence of mobile phone radiation on honeybees. In the experiments, they used two test colonies with two mobile phones (900 MHz, average transmitting power of 8.549 µW/cm2 and an electric field of 56.8 V/m) placed inside each hive. Apart from that, a blank colony had two dummy phones placed inside the hive and a control colony had no mobile phones. The colonies were exposed twice per day for 15 minutes, twice per week. Measurements were made before and during exposure, over a period of three months. The results indicate a strong effect of the mobile phone radiation with about 30 % decreases in numbers of worker bees leaving and returning to the hive during exposure compared to before exposure. Brood area, egg laying rate of the queen, honey stores were even very severely reduced (by approximately 70% after 3 months).

> Sharma and Kumar, 2010
>
> - Effect of EMF from mobile phones on behaviour of honey bees
> - Negative influence by exposure (decline colony strength and egg laying rate of the queen)
>   - Unreliable article

A major flaw in these experiments is the small sample size, with only two exposed colonies. The measurements are presented with standard deviations but they seem not so meaningful with so few colonies measured. Moreover, the mobile phones were placed within the bee hives which probably leads to much higher radiation intensities than in a natural situation, especially within the hives. The article itself is rather well-written for the biggest part, though perhaps not up to the standards of most well-known international scientific journals. What is exceptional is that the first two sentences of the abstract claim the following: "Increase in the usage of electronic gadgets has led to electro pollution of the environment. Honeybee behaviour and biology has been affected by electro smog since these insects have magnetite in their bodies which helps them in navigation." These claims are not dealt with in the body of the article and are not supported by references. The final sentences also seem subjective, where the authors suggest that developing countries have not experienced the recent declines in honeybees because there are less EMF-based technologies present in these countries. The final sentence states that strategies should be timely planned in order to "save not only the bees but life from the ill effects of such EMR." This suggests that the authors are not objective in this. This questions the ability to accurately observe the differences between exposed and non-exposed colonies, since prejudices might lead to exaggeration. The references of the article seem to be unreliable as well, many internet sources were used. Furthermore, authors like Warnke, Stever and Kuhn are cited, their work is discussed in this chapter as well and we judge it as being unreliable. Although the authors start with introducing colony collapse disorder (CCD) they do not cite any of the many existing papers on the topic. Notable is that the article was actually peer-reviewed. It was published in the Indian journal Current Science and it can be read on their website that a peer-review system is used. The peer-review of the journal seems to be inadequate in our opinion since an article like this should not be accepted by an international scientific journal of high quality. To conclude, the flaws in the experimental set-up as well as the supposed bias of the authors towards EMF being dangerous, the information in this article is thought to be unreliable.

5.4 Information from websites on EMF and honeybees

Besides literature review, other sources such as web pages were consulted. The criteria used to judge the quality of the information in the visited web sites can be summarized in:

- Publisher: individuals, governmental organizations, non-governmental organizations, educational institutes like universities, companies or commercial publishers.
- Accuracy: documented facts, traceability of information sources.
- Objectivity: objective of the document, type of information (opinion, facts, propaganda, etc.). Information about the sponsors of the page.
- Authors: authors, background and reputation of the web page.
- Actuality: originally written date, last review, broken links. Today's date review can be generated automatically, so this is not taken into account for updating purposes.

Evaluated Websites

The following pages were consulted in order to get an overview of the discussion on possible effects of EMF in honeybees and other living organisms.

H.E.S.E. Project (www.hese-project.org)
The h.e.s.e. project (Human Ecological Social Economic) is a non-governmental institution. They describe themselves as an union of interdisciplinary scientists and scientific institutions that work in different environmental fields. It is not possible to find who are those scientist and what their background is. Furthermore, it is not possible to determine from the web page the background of the web page's authors to evaluate their suitability for discussing the topics discussed in the website. One of the issues presented in the page is the negative effects of EMF on honeybees. Most of the documents on this topic have information about the sources and authors. Additional contact information about the sources is presented and this makes it possible to trace back the sources. As mentioned before, the information and opinions placed in the page are on the negative effects of EMF, but in the link to become part of the group they request, the objectivity of the scientist in order to provide convincing arguments about the discussed topics. The organization is founded by sponsoring and donations but it is not clear who those individuals or organizations are, consequently we cannot state if there are other motivations and interests different from the ones that are expressed in the page. About the actuality of the page it was possible to find the date when the page was started (31-Aug-2002) and the latest review. In general, it is possible to determine dates of news and documents, but this is mostly applicable for the original page in German. For comments and statements in the other language pages this information is not always consistent. The visited links worked properly although some sections do not present any information. In conclusion, we asses this webpage as subjective and we doubt about the reliability of its comments and statements because it is not possible to judge the background of the mentioned scientists group.

Stay on the truth (www.stayonthetruth.com)
It was not possible to state what kind of organization or person is behind Stay on the Truth because no information about the authors and sponsors of the page is presented. Moreover, they are registered with "whoisguard", a system to prevent others to know the real author of the web page. What it is clear, is that the authors think EMF is harmful. Some documents presented in this web page correspond to journals and traceable publications but some others are presented as abstracts of publications, but they are not. They lack minimum information like date of publication, journal, issue, number and other information that allows to identify the document. Moreover it is not possible to trace back the creation dates of the documents and opinions stated in the website. Due to the previous reasons and difficulty to state the authors of the page and its background, this webpage can be qualified as not reliable.

EMRX (www.emrx.org)
The first impression of this page is that you can trust it because it presents clear information about the author, its background and contact information. Mr. Bowling is known as a strong opponent of EMF in the environment. He presents himself as public speaker, author, consultant,

public advocate and activist, but none of this can help us to see the technical background required to state, in an objective way, the effects of EMF. The aim of the page seems to be mainly commercial, DVD's, books about the negative effects of EMF and products for preventing the radiation are promoted in this site. The information and documents that comment on the studies about negative effects of EMF are not possible to track, because documents and statements are referred to HANS consultant and the Clean Energy Foundation (www.cleanenergycanada.com), who is in fact the same author of EMRX. About bees, two articles are presented: Where are the Birds and Bees? and Bees and the Future of Food, both articles mention EMF as cause of colony losses, but they just represent the opinion of the author of the page. In the references HANS consultant and the Clean Energy Foundation appear as consulted sources. In conclusion, this page is not recommended to be used as a reliable source on the effects of EMF.

In this chapter, we discussed articles and websites on effects of EMF on honeybees. We concluded that research on the effects of high power lines (low-frequency radiation) is reliable, and shows a negative effect on honeybees, although local. Other studies showed effects of EMR on the waggle dance in bees. These studies were of reasonably good quality, although some aspects of the material and method section were unclear.

Unfortunately, the studies that are most important to answer our question are all of low quality. Material and methods are often inappropriate, or not described properly. The background of the authors is doubtful for research on bees, and in some cases the authors seem biased. These articles are unsuitable for answering our question. Also websites on the topic seem to be biased. Sometimes, references are made to one or more of the articles we discussed in this chapter, and often statements about the effects of EMF are made without references at all.

6. Discussion

In this study we have tried to investigate possible effects of EMF on honeybees, to assess the current state of the knowledge on the topic and to identify knowledge gaps. We stated that the problem was that it is difficult to get an insight in whether or not honeybees are harmed by EMF, because the quality of much of the information on this topic seemed to be questionable and/or biased. To tackle this problem we posed three questions with several sub-questions. The answers to these questions are discussed in the following paragraphs.

To stress the importance of getting a better understanding of the topic, 80% of European citizens have the feeling that they are not well informed on potential health risks of EMF (European Commission, 2007a). The scientific community seems to have often not taken the concerns of the public into account, especially regarding the effects of EMF on the environment. Policy makers have taken steps to inform the public (for example by providing information from WHO and ICNIRP on the internet). However, they did not change policy and did not manage to take away all public fears, partly due to contradictory findings and the lack of reliable information and perhaps also due to the complexity of the topic. These attitudes have led to the founding of many advocacy groups, that in principle represent the opinion of the public that wants to make itself heard. Furthermore, the media have contributed to the spread of public concerns and polarization of the debate. When objective, one must conclude that negative effects of EMF on health and the environment cannot be ruled out. However, most of the stakeholders do take a position in the debate and express their (often biased) opinion.

While conducting the literature study, we came across numerous interesting publications but often the backgrounds and the material and methods section were not easily understood due to technical aspects. In some cases an expert advice could have been helpful. Therefore scientific studies in the field of EMF are complex and require basic knowledge in physics and biology. Nevertheless, we were able to get an insight in this subject which made us aware of pitfalls in certain articles. For example, a number of authors do not have a background in physics or (honeybee) biology which results sometimes in mistakes or missing links which confuse the reader. We have tried to pinpoint the knowledge gaps in this field.

To reach the literature assessment objectives, we have divided the sub-topics to be studied among group members. Depending on the content of the different chapters, relevant information was selected and studied. The articles on EMF and honeybees which were evaluated in chapter 6 were read extra carefully by one group member prior to discussing it. That group member also looked into the backgrounds of the article and retrieved information on the author and journal of publication. He or she then led the discussion and evaluation of the article according to the defined criteria. We found this a suitable way of assessing the quality and reliability of the information, although it seems inefficient in case a large amount of information needs to be assessed, and perhaps certain criteria were not suitable for all articles.

According to the small amount of time we had, our procedure gave satisfactory results and enabled us to draw conclusions and give comments.

6.1 Possible harmful effects of EMF on honeybees

One of our main questions was if and how honeybees could be harmed by EMF. We have looked into the available information on EMF effects in other organisms in general and magnetoreception in honeybees to see if we could find any clues for answering this question.

Effects on other organisms

The research done on effects of EMF other organisms contains a lot of contradictory results. However, there is some reliable literature available on thermal effects in mammals and non-thermal effects in *Drosophila*, birds and plants. It has been shown that EMF can cause thermal effects like a deficit in learning behaviour and increased incidences of feutal malformation (Vecchia *et al*., 2009). But, thermal effects on honeybees are expected to be small or absent, unless the radiation source is very close to the hive. Possible non-thermal effects that were shown in *Drosophila* studies include increased transcription of a stress factor (*hsp70*) and negative effects on development and reproduction. Similar effects can be expected in brood development in honeybee colonies, although that would highly depend on the field strength, which would in most areas not be so high in natural situations. A study on birds suggested that EMF influences the orientation of birds (Thalau *et al*., 2005) and therefore possible effects on honeybee navigation could be expected as both birds and honeybees make use of magnetite and a chemical reception system based on a radical pair mechanism for magnetoreception (Wiltschko and Wiltschko 2010). Also in plants, studies on the influence of EMF on plants show that there might be an effect (Tafforeau *et al*., 2006; Vian *et al*., 2006). However, EMF effects on plants as described in this report could not give more insight in if and how bees could be affected as the mentioned effects are not expected to occur in honeybees.

Magnetoreception

Based on the recent increase in the knowledge on magnetoreception (Hsu *et al*., 2007; Gegear *et al*., 2010; Wajnberg, 2010; Winklhofer, 2010), it is thought that navigation by the Earth magnetic field might play a considerable role in navigation by honeybees as well. This has made us hypothesize that EMF might possibly be influencing navigation in honeybees, in case it would interfere with their perception of the Earth magnetic field. This would probably lead to impairment of homing ability and communication of the position of a food source through the waggle dance. It is known for a while that worker bees make small systematic errors in the waggle dance that seem to follow daily variations in the Earth magnetic field (Gould and Gould, 1988). Errors in the waggle dance from effects of ELF radiation were also found in some studies (Korall *et al*., 1987; Martin *et al*., 1988) but further studies would be necessary to confirm this. Therefore, we think it makes sense to focus research activities on effects of EMF on navigation and the waggle dance. Recommendations on this are made in paragraph 6.3. But, knowledge gaps in the field of magnetoreception could frustrate the research. Many aspects of the mechanisms that are used by animals to sense magnetic fields remain poorly understood as of yet. This can make it difficult to understand how differences in magnetic field strength and influences of artificial (electro-)magnetic fields could have an impact on the magnetic sense in honeybees and other organisms. It might therefore be difficult to delimit the possible factors that might have an influence and to focus studies on a certain mechanism of magnetoreception. However, we think it is possible to set up hypotheses to test if man-made EMF would have an influence on navigation or not, so as to provide clues for further studies.

6.2 Discussion of the current knowledge

A second question that we posed at the start of the project, was related to the quality and reliability of the literature. What we found, is that recent research on influences of EMF in the radio frequency range on bees is not reliable. There are in fact only two independent groups that researched it: one from the University of Koblenz-Landau in Germany (Stever and Kuhn, 2003; Harst *et al*., 2006; Kimmel *et al*., 2007) and one from Panjab University in India (Sharma and Kumar, 2010). Both groups, in their experiments, have placed a source of radiation inside the hive. Since that could lead to high exposure levels in the bees, perhaps thermal effects could have played a role. In any case, the number of observations was low and the studies are unreliable overall, as was concluded in the previous chapter. Apart from those two groups, the work of Warnke (2009) also does not provide any reliable experimental results on radio frequency radiation. So we cannot draw any conclusions on possible hazards to bees from the increasing use of wireless communication technologies.

Older studies on the influences of extremely low frequency (ELF) radiation were found to be more reliable. High tension power lines can have local adverse effects in the beehives, but the effects quickly diminish with distance to the power lines (Greenberg *et al*., 1981). Bindokas *et al*. (1988a and b, 1989) show that this is mainly due to changes in behaviour (stinging) and electric shock and only occurs when the bees are in contact with a conducting medium. Korall *et al*. (1987) and Martin *et al*. (1988) show that artificial low frequency magnetic fields also can affect the waggle dance, which suggests possible impairment of navigation in honeybees. These studies support hypotheses that EMF can influence honeybees. The latter support the hypothesis that it can specifically influence their navigation. This points to a clear knowledge gap on the influences of EMF of higher frequencies, especially those from the radio frequency (RF) range that are produced by mobile phones, WiFi and the likes.

Because of the lack of knowledge on the influence of EMF on bees, it is also not known whether CCD could be related to EMF. Recent research on CCD is focused on pathogens, especially on the relationship between the *Varroa* mite and viruses, as this is regarded as a more likely explanation of colony losses than other factors such as genetically modified crops, beekeeping practices, nanotechnology and EMF. However, it is important to also study less likely causes, as they may be influencing the health of honeybees as well.

EMF might play a role in colony losses, for example when the navigation capability of bees would be impaired, or if the overall condition of bees decreases, as a consequence of EMF. The overall condition of bees determines the susceptibility of a colony to pests such as V*arroa*. It was shown that low-frequency radiation can be harmful for bees, although the effect is local. Moreover, research on effects of high frequency EMR on other organisms suggests that this type

of radiation might be harmful, so we should not discard this as a possibly contributing cause of colony losses before more research has been done. Effects of EMF on bees will probably be local, so if EMF plays a role in colony losses one would expect to find a correlation between occurrence of colony losses and use of mobile communication devices around the world. This is not indicated by reports of colony losses, as it is reported from both regions with high and low levels of EMF in the environment, and the other way around, no losses on the southern hemisphere (Neumann & Carreck, 2010) whilst mobile phones are used a lot there.
Nevertheless, we do not expect EMF to be a direct nor a major cause of colony losses. If EMF plays a role in colony losses, it will most likely be a combination between EMF and other factors.

6.3 Recommendations

From the understanding we got in this study, it is possible to make recommendations for future research, taking into consideration that we are not experts in the field of EMF. For this reason our recommendations will need further approval among specialists to be integrated in a research proposal. It would be preferable to tackle the research question (is EMF harmful to bees?) by a multidisciplinary group who can complement each other in expertise in different aspects (honeybee biology, EMF and physics).
In our literature study we have found that many sources are unreliable, often because the authors seemed to be biased. A first recommendation would therefore be to always use decent methods for making observations in experiments. Doing it blind or (even better) double blind is recommended in case it is not possible to automate observations. Furthermore, researchers should be aware of the stakeholders as they might be able to influence the results.
Another problem in experimental methods that should be avoided is using different measurement units or not even measuring the field strength at all. There are many sources of EMF which makes measurements and experiments related with electromagnetic fields complex. There are many variables that can affect the final results of the experiments. Therefore special care has to be taken while setting up experiments in this topic. Measurements should be taken at different times during the experiments, because field strengths will often be variable through time. It is recommended to measure both the electrical field strength (in V/m) and the magnetic field strength (in A/m or Tesla) to make sure that results from different studies can be compared.
Of the possible influences of EMF on honeybee behaviour, we recommend that the aspect of navigation deserves most attention. There are many ways to study effects on navigation, some recommendations on different parts of possible experimental approaches are given here. The easiest way to see if bees would be affected in their navigation, is to look at returning behaviour when hives are placed within different field strengths. This has also been attempted in previous studies (e.g. Kimmel *et al*., 2007; Sharma and Kumar, 2010), but observations were not done in a reliable way. A drawback of studying returning behaviour like this is also that many other environmental factors could influence the returning behaviour. Perhaps a better way to see if there are influences on navigation would be to look at the waggle dance. From the waggle dance, the angle and distance to the food source can be deduced. In case the location of the food source is known, it would be possible to see if EMF from mobile phone base stations would

cause mistakes in communication through the waggle dance. That would provide good clues on whether or not the bees are influenced in their navigation. One can imagine experiments with a feeding table and different intensities and/or frequencies of GSM or UMTS radiation.
Moreover, influences of EMF on the returning behaviour of honeybees have so far only been studied with differences in magnetic field strengths around the hive. In these studies, bees from non-exposed hives might still have to navigate through EMF to reach the food source or to return to the hive to a similar extent as bees from exposed hives. Bees might use magnetic fields for navigation predominantly when they are at a considerable distance from the hive. A suggestion would therefore be to study the influence of magnetic fields around the food source. In this way it can be studied if bees would become disoriented and lose their way during foraging when flying through EMF. This could perhaps also best be done in experiments with a feeding table, where possible influences on the waggle dance can be studied.
The best would probably be to study bee behaviour in controlled environments with and without EMF, for example in greenhouses. In this way, other factors that could cause differences between exposed and non-exposed colonies could be minimized. But it is also more costly than experiments in the open field. But a greenhouse would probably be not large enough to induce waggle dancing.

To be able to get a good insight in the question whether or not EMF is harmful for honeybees, it will not be enough to have one study or only studies from the same group. Multiple independent research projects would be needed, and comparison of the results would have to make it possible to reach consensus. Chances are, however, that contradictory results will be found, like in many studies on EMF effects on health and the environment. It should be avoided that contradictory results are caused by different approaches to making observations and measuring field strengths. In other words, comparability among studies is very important for reaching consensus on the risks of EMF on honeybees.

Our recommendations regarding the public debate is that the scientific community, policy makers and others as the WHO should take the lead in communicating reliable information. The public should have the feeling that their concerns are taken into account. It would also be good to explain why certain studies are not reliable so that the public can make a better judgement themselves on speculative information that is circulating. A next step would be to do proper research, as is stressed before and then to also communicate these results to the public. For this one should be aware of stakeholders and the media that might reformulate the findings for their own advantage or for sensationalism.
Recommendations for advocacy groups are to carefully select their sources. We have shown in chapter 5 that most of the recent articles on EMF and honeybees are not reliable and referencing to those authors would make an advocacy group less credible. We think it is important for advocacy groups to have credibility in order to gain recognition, voice and power regarding EMF effects on health and the environment.

6.4 Conclusion

We have assessed and given an overview of the available literature on the topic. From this we found that honeybees can hypothetically be affected by EMF in their navigation. There is scientific evidence for local adverse effects from high tension power lines on bee colonies, including stinging behaviour and electric shock when the bees are in contact with a conducting medium. Studies also point out effects on the waggle dance, where artificial ELF-fields and compensation of the Earth magnetic field induce misdirection and a lower dance tempo, respectively. Reliable scientific literature on effects from EMF in the radio frequency range (30 KHz-300 GHz) is completely lacking. This means that no conclusions can be drawn on effects from the increasing use of wireless communication technologies. We can also not conclude anything on the suggestion that EMF might cause or contribute to colony losses, though it seems likely not be a major cause of it. In any case, further research is necessary to gain more understanding of possible harmful effects of EMF on honeybees. We hope that our recommendations can be of help in further studies.

Acknowledgements

We first of all would like to thank our coach, Ellen van Velthoven, for guiding and improving the functioning of the team. We want to thank Hugo Hoofwijk, our commissioner, for the pleasant collaboration and constructive comments. Tjeerd Blacquière, bee-scientist at PRI, was a very important contributor to the report. He helped us a lot with getting an understanding of the backgrounds of honeybees and colony losses. His colleagues, Sjef van der Steen and Bram Cornelissen also provided help during the period in which he was abroad. After having inquired at different places for assistance on the theoretical backgrounds on EMF, we finally found Natascha Staats, working at Milieu Centraal, to be willing to provide us with information and comments on that part. Corrie van Zeist, working at WUR Library, is thanked for help with information retrieval.

References

Aldrich, T.E., Easterly, C.E. (1987)'Electromagnetic Fields and Public Health', *Environmental Health Perspectives* 75: 159-171, available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1474448/pdf/envhper00434-0152.pdf (accessed: 30 December 2010).

Alpen, E.L. (1998) *Radiation Biophysics*. Second edition. San Diego: Academic Press.

Balmori, A. (2005) 'Possible effects of electromagnetic fields from phone masts on a population of White Stork (*Ciconia ciconia*)', *Electromagn. Biol. Med.* 24:109-119.

Beere, H., Wolf, B., Cain, K., Mosser, D., Mahboubi, A., Kuwana, T., Tailor, P., Morimoto, R., Cohen, G., and Green, D. (2000) 'Heat shock protein 70 inhibits apoptosis by preventing recruitment of procaspase-9 to the Apaf-1 apoptosome', *Nat. Cell Biol*. 2: 469–475.

Beespotter (2010). 'The importance of honey', available at: http://beespotter.mste.illinois.edu/topics/honey/Honey.html (accessed on: 10 November 2010).

Bijen@wur (2010) 'Varroa destructor', available at www.varroa.wur.nl (accessed: 29 November 2010).

Bioelectromagnetic society (2010) 'Bioelctromagnetics journal', available at https://www.bems.org/journal (accessed: 8 December 2010).

Bindokas, V.P., Gauger, J.R., Greenberg, B. (1988a) 'Exposure Scheme Separates Effects of Electric Shock and Electric Field for Honey Bees, *Apis mellifera* L.', *Bioelectromagnetics* 9:275-284.

Bindokas, V.P., Gauger, J.R., Greenberg, B. (1988b) 'Mecahnism of Biological Effects Observed in Honey Bees (*Apis mellifera*, L.) Hived Under Extra-High-Voltage Transmission Lines: Implications Derived From Bee Exposure to Simulated Intense Electric Fields and Shocks', *Bioelectromagnetics* 9:285-301.

Bindokas, V.P., Gauger, J.R., Greenberg, B. (1989) 'Laboratory Investigations of the Electrical Characteristics of Honey Bees and Their Exposure to Intense Electric Fields', *Bioelectromagnetics* 10:1-12.

Blacquière, T., van der Steen, J.J.M., Cornelissen, A.C.M. (2009) 'Visie bijenhouderij en insectbestuiving: analyse van bedreigingen en knelpunten', Report 227, Plant Research International, 64 pp.

Breed, D.M., Williams, K.R., Fewell, J.H. (1988) 'Comb wax mediates the acquisition of nest-mate recognition cues in honey bees', *Population Biology* 85: 8766-8769.

Costa, H. S., Robb, K. L. (1999) 'Effects of ultraviolet-absorbing greenhouse plastic films on flight behavior of *Bemisia argentifolii* (Homoptera: Aleyrodidae) and *Frankliniella occidentalis* (Thysanoptera: Thripidae)', *J. Econ. Entomol.*92:557 -562.

Costa, H. S., Robb, K. L.,Wilen, C. A. (2002)'Field trials measuring the effects of ultraviolet-absorbing greenhouse plastic films on insect populations', *J. Econ. Entomol.*95:113.

De Castro, S.L. (2001) 'Propolis: Biological and Pharmacological Activities. Therapeutic Uses of this Bee-product', *Annual Review Biomedical Science* 3: 49-83.

Dyer, A.G.,Chittka, L. (2004)'Bumblebee search time without ultraviolet light', *J. Exp.Biol.* 207: 1683-1688.

Edmonds, D. T. (1996) 'A Sensitive Optically Detected Magnetic Compass for Animals', *Proceedings of the Royal Society B: Biological Sciences* 263(1368): 295-298.

EMF Explained Series (2010) 'What is EMF?-L2'available at: http://www.emfexplained.info/?ID=25192 (accessed: 25 November 2010).

Emlen, S.T. (1975) *Migration: Orientation and navigation*. New York: Academic Pressobins.

Ericsson (2007) 'Radio frequency exposure and health', available at: http://www.ericsson.com/ericsson/corporate_responsibility/health/ (accessed: 1 December 2010).

Everaert, J., Bauwens, D.(2007) 'A possible effect of electromagnetic radiation from mobile phone base stations on the number of breeding house sparrows (Passer domesticus)', *Electromagnetic biology and medicine*26(1): 63-72.

European Commission (2007a) 'Electromagnetic Fields', Special Euro barometer 272a/Wave 66.2- TNS Opinion & Social, available at http://ec.europa.eu/public_opinion/archives/ebs/ebs_272a_en.pdf (accessed: 30 November 2010).

European Commission (2009) 'Electromagnetic field emission addressed by EU standards', The magazine of Enterprise policy, available at http://ec.europa.eu/enterprise/e_i/news/article_9101_en.htm (accessed: 30 November 2010).

Gegear, R. J., Foley, L. E. , Casselman, A., Reppert, S.M. (2010) 'Animal cryptochromes mediate magnetoreception by an unconventional photochemical mechanism', *Nature* 463(7282): 804-807.

Goodman, R., Weisbrot, D., Uluc, A., Henderson, A. (1992a) 'Transcription in *Drosophila melanogaster* salivary gland cells is altered following exposure to low frequency electromagnetic fields: Analysis of chromosome 3R', *Bioelectromagnetics* 13:111–118.

Goodman, R., Weisbrot, D., Uluc, A., Henderson, A. (1992b) 'Transcription in *Drosophila melanogaster* salivary gland cells is altered following exposure to low frequencyelectromagnetic fields: Analysis of chromosomes 3L and X', *Bioelectrochem Bioenerg* 28:311–318.

Gould, J.L., Gould, C.G. (1988) *The honey bee*. New York: Scientific American Library.

Greenberg, B., Bindokas, V.P., Gauger, J.R. (1981) 'Biological Effects of 765-kV Transmission Line: Exposures and Thresholds in Honeybee Colonies', *Bioelectromagnetics* 2:315-328.

Grigoriew, J.G. (2003) 'The influence of electromagnetic fields from mobile phones on chicken embyo's', *Journal für Strahlungs-Biologie* 5:541-544.

Gruter, C, Farina, W.M. (2009) 'The honeybee waggle dance: can we follow the steps?' *Trends in Ecology and Evolution* 24(5) 242-247.

Hardell, L., Sage, C. (2008) 'Biological effects from electromagnetic field exposure and public exposure standards' *Biomedicine & Pharmacotherapy* 62: 1-6.

Harst, W., Kuhn, J., Stever, H. (2006) 'Can electromagnetic exposure cause a change in behaviour? Studying possible non-thermal influences on honey bees – An approach within the framework of educational informatics', *IIAS International Journal* 6(1): 1-6.

H.e.s.e.-project. (2010a). 'Topical issues: Decline of bees, UK and worldwide', available at http://bemri.org/hese-uk/en/issues/nature3e83.html?id=bees (accessed: 6 December 2010).

H.e.s.e.-project. (2010b). 'Who is behind the h.e.s.e. Project in the UK?', available at http://bemri.org/hese-uk/en/heseuk/profilee626.html?id=hst (accessed: 6 December 2010).

High Frequency Active Auroral Research Program, 2010. 'Program Purpose', available at http://www.haarp.alaska.edu/haarp/gen.html (accessed: 3 December 2010).

Hsu, C., Ko, F., Li, C., Fann, K., Lue, J. (2007) 'Magnetoreception System in Honeybees (*Apis mellifera*)', *PLoS ONE* 4 e395.

International Commission on Non-Ionizing Radiation Protection (2010) 'Guidelines for limiting exposure to time-varying electric and magnetic fields (1Hz-100KHz)', *Health Physics* 99(6):818-836.

Kevan, P.G. (2007) 'Bees biology & management' Cambridge, Ontario: Enviroquest Ltd, 345 pp.

Kimmel, S., Kuhn, J., Harst, W., Stever, H. (2007) 'Electromagnetic Radiation: Influences on Honeybees (*Apis mellifera*)' IIAS – Intersymposium conference, Baden-Baden.

Kirschvink, J. L., Padmanabha, S., Boyce, C. K., Oglesby, J. (1997) 'Measurement of the threshold sensitivity of honeybees to weak, extremely low frequency magnetic fields', *J. Exp.Biol.* 200: 1363–1368.

Kirschvink, J. L., Walker, M. M., Diebel, C. E. (2001). 'Magnetite-based magnetoreception', *Curr. Opin. Neurobiol.* 11: 462–467.

Klein, A.M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremens, C., Tscharntke, T. (2007) 'Importance of crop pollinators in changing landscapes for world crops' *Proceedings of the royal society* B 274: 303-313.

Korall, H., T. Leucht & H. Martin. (1988). Bursts of magnetic fields induce jumps of misdirection in bees by a mechanism of magnetic resonance. J. Comp. Physiol. A 162: 279-284.

Kumlin, T., Tinoven, H., Miettienen, P., Juvonen, A., Van Groen, T., Puranen, L., Pitkäaho, R., Juutilainen, J., Tanila, H. (2007) ' Mobile phone radiation and the developing brain: behavioural and morphological effects in juvenile rats', *Radiat Res* 168:471–479.

Kwak, M.M., Velterop, O. & van Andel, J. (1998) 'Pollen and gene flow in fragmented habitats.' Applied vegetation Science Vol. 1, No. 1, 37-54

Le Conte, Y., Ellis, M., Ritter, W. (2010) '*Varroa* mites and honey bee health: can varroa explain part of the colony losses?' *Apidologie* 41: 353-363.

Liedvogel, M. Mouritsen, H. (2010) 'Cryptochromes – a potential magnetoreceptor: what do we know and what do we want to know?', *Journal or the Royal Society Interface* 7: 147-162.

Lohmann, K.J., Lohmann, C.M.F. (1996) 'Orientation and open-sea navigation in sea turtles', *Journal of Experimental Biology*199*:* 73-81.

Mae-Wan Ho, institute of science in society (2004)'Electromagnetic Fields of Influence (EMF)', available at http://www.mindfully.org/Technology/2004/EMF-Electromagnetic-Fields15dec04.htm (accessed: 30 November 2010).

Martin, H., Korall, H., Förster, B. (1988) 'Magnetic field effects on activity and ageing in honeybees', *Journal of comparative physiology A* 164 (4):423-431.

Milieu Centraal. (2010). 'Electromagnetische velden', available at: http://www.milieucentraal.nl/pagina.aspx?onderwerp=Elektromagnetische%20velden (accessed: 8 December 2010)

Mikkelson, B., Mikkelson, D.P. (2007) 'Einstein on bees', available at http://www.snopes.com/quotes/einstein/bees.asp (accessed: 10 December 2010)

Mobichippxd, 'Invloed van straling op de gezondheid', available at: http://www.mymobichip.nl/gsm-straling-gezondheid.php (accessed: 1 December 2010).

Moore, F.R. (1987)'Sunset and the orientation behavior of migratory birds', *Biological Review* 62*:* 65-86.

Morandin, L. A., Laverty, T. M.,Kevan, P. G. (2001) 'Bumble bee (Hymenoptera: Apidea) activity and pollination levels in commercial tomato greenhouses', *J. Econ. Entomol.*94: 462-467.

NASA (2010) 'Electromagnetic spectrum', available at: http://mynasadata.larc.nasa.gov/ElectroMag.html(accessed: 25 November 2010)

Neumann, P., Carreck NL. (2010) 'Honey bee colony losses', *Journal of Apicultural Research* 49(1):1-6.

Nokia, 'Mobile communications & health', available at http://www.nokia.com/corporate-responsibility/emf-and-health/mobile-communications-and-health (accessed: 1 December 2010).

Oldroyd, B.P. (2007) 'What's killing American honey bees?', *PloS Biology* 5:1195-1199.

Page, R.E., Peng, C.Y. (2001) 'Aging and development in social insects with emphasis on the honey bee, *Apis mellifera'*, *L. ExpGerontol* 36: 695–711.

Panagopoulos, D.J., Karabarbounis, A., Margaritis, L.H. (2004) 'Effect of GSM900-MHz Mobile Phone Radiation on the Reproductive Capacity of *Drosophila melanogaster'*, *Electromagnetic Biol Med* 23(1):29–43.

Phillips, J.B. (1986) 'Two magnetoreceptor pathways in a migratory salamander', *Science* 233: 765-767.

Phillips J. B., Waldvogel J. A. (1988) 'Celestial polarized patterns as a calibration reference for sun compass of homing pigeons', *J. Theor. Biol. 131: 55–67.*

Phillips, J. B., Schmidt-Koenig, K., Muheim, R. (2006) 'True navigation: sensory bases of gradient maps'. A*nimal Spatial Cognition: Comparative, Neural, and Computational Approaches,* Available at: www.pigeon.psy.tufts.edu/asc/phillips/ (accessed on 25 November 2010).

Phillips, J. B., Jorge, P. E., Muheim, R. (2010) 'Light-dependent magnetic compass orientation in amphibians and insects: candidate receptors and candidate molecular mechanisms', *Journal of The Royal Society Interface* 7(Suppl_2): S241-S256.

Ratnieks, F.L.W., Carreck NL. (2010) 'Clarity on honey bee collapse?', *Science* 327:152-153.

Rijksoverheid. 'Antennes en gezondheid', available at http://www.rijksoverheid.nl/onderwerpen/antennes/antennes-en-gezondheid (accessed: 1 December 2010).

Ritz, T., Wiltschko, R., Hore, P.J., Rodgers, C.T., Stapput, K., Thalau, P., Timmel, C.R., Wiltschko, W. (2009) 'Magnetic Compass of Birds Is Based on a Molecule with Optimal Directional Sensitivity', Biophysical Journal 96(8): 3451-3457.

Schmidt-Koenig, K. (1990) 'The sun compass', *Experientia*16: 336–342.

Schmidt-Koenig, K. (1979) 'Directions of migrating monarch butterflies *(Danaus plexippus;* Danaidae; Lepidoptera) in some parts of the eastern United States', *Behav. Processes* 4: 73-78.

Schmutz, P., Siegenthaler, J., Stäger, C., Tarjan, D., Bucher, J.B. (1996) 'Long-term exposure of young spruce and beech trees to 2450-MHz microwave radiation', *The Science of the Total Environment* 180: 43-48.

Sharma, V.P., Kumar, N.R. (2010) 'Changes in honeybee behaviour and biology under the influence of cell phone radiations', *Current science* 98 (10): 1376-1378.

Stever, H. (2002). 'Theorie der Superzeichen im Rahmen der Bildungsinformatiek', *Grundlagenstudien aus Kybernetik und Geisteswissenschaft* 43: 9-15.

Stever, H., Kuhn, J. (2004). 'How electromagnetic exposure can influence learning processes – Modelling effects of electromagnetic exposure on learning processes', *IIAS-Transactions on Systems Research and Cybernetics: International journal of the International Institute for Advanced Studies in Systems Research and Cybernetics* 4(1): 1-10.

Tafforeau, M., Verdus, M.C., Norris, V., Ripoll, C., Thellier, M. (2006) 'Memory processes in the response of plants to environmental signals', *Plant Signaling & Behavior* 1:9-14.

Thalau, P., Ritz, T., Stapput, K., Wiltschko, R., Wiltschko, W. (2005) 'Magnetic compass orientation of migratory birds in the presence of a 1.315 MHz oscillating field', *Naturwissenschaften* 92:86-90.

Van Engelsdorp, D., Evans, J.D., Saegerman, C., Mullin, C., Haubruge, E., Nguyen, B.K., Frazier, M., Frazier, J., Cox-Foster, D., Chen, Y., Underwood, R., Tarpy, D.R., Pettis, J.S. (2009) 'Colony Collapse Disorder: A Descriptive Study', *PLoS ONE 4*(8):e648:1-17.

Velthuis, H.H.W. & van Doorn, A. (2006) A century of advances in bumblebee domestication and the econiomic and environmental aspects of its commercialization for pollination. Apidologie 37, 421-451

Vian, A., Roux, D., Girard, S., Bonnet, P., Paladian, F., Davies, E., Ledoigt, G. (2006), 'Microwave irradiation affects gene expression in plants', *Plant Signaling&Behavior*1:2, 67-70.

Viuda-Martos, M., Ruiz-Navajas, Y., Fernádez-López, J., Pérez-Álvarez, J.A. (2008) 'Functional Properties of Honey, Propolis, and Royal Jelly', *Journal of Food Science* 73 (9): 117-123.

Van Vlijmen, O. (2003). 'Straling bij GSM', available at http://home.kpn.nl/vanadovv/StralGSM.html (accessed: 1 December 2010).

Vecchia, P., Matthes, R., Ziegelberger, G., Lin, J., Saunders, R., Swerdlow, A. (2009) 'Exposure to High Frequency Electromagnetic Fields, Biological Effects and Health Consequences (100 kHz-300 GHz)' *ICNIRP 16/2009*.

Wajnberg, E., Acosta-Avalos, D., Alves, O.C., de Oliveira, J.F., Srygley, R.B., Esquivel, D. M. S.(2010) 'Magnetoreception in eusocial insects: an update', *Journal of The Royal Society Interface* 7(Suppl_2): S207-S225.

Warnke, U. (2009) 'Bees, birds and mankind: destroying nature by 'electrosmog' – Effect of wireless communication technolgies', Brochure series by the competence initiative for the protection of humanity, environment and democracy, brochure 1.

Weisbrot, D., Lin, H., Ye, L., Blank, M. and Goodman, R. (2003) 'Effects of mobile phone radiation on reproduction and development in *Drosophila melanogaster'*, *Journal of Cell Biochemistry* 89:48–55.

Wellenstein, G. (1973) 'Der Einfluß von Hochspannungsleitungen auf Bienenvölker (*Apis mellifera* L.). Zeitsch. Angewandte Entomologie 74, 86-94.

Wiltschko, W., Wiltschko. R. (1972)'Magnetic compass of European robins', *Science* 176: 62-64.

Wiltschko, R., Wiltschko, W. (1995). *Magnetic orientation in animals*. Berlin: Springer-Verlag.

Wiltschko, W., Wiltschko, R. (2005) 'Magnetic orientation and magnetoreception in birds and other animals', *Journal of Comparative Physiology A* 191:675–693.

Wiltschko, R., Stapput, K, Thalau, P., Wiltscko., W. (2009) 'Directional orientation of birds by the magnetic field under different light conditions', *Journal of The Royal Society Interface* 7(Suppl_2): S163-S177.

Winklhofer, M. (2010) 'Magnetoreception', Journal of The Royal Society Interface 7(Suppl_2): S131-S134.

Winklhofer, M., Kirschvink, J. L. (2010) 'A quantitative assessment of torque-transducer models for magnetoreception' *Journal of The Royal Society Interface* 7(Suppl_2): S273-S289.

Winston, M.L. (1987) 'The biology of the honeybee, *Apis mellifera*', Cambridge: Harvard University Press.

World Health Organization (2010a) 'Electromagnetic fields & public health: Intermediate Frequencies (IF)', available at http://www.who.int/peh-emf/publications/facts/intmedfrequencies/en/ (accessed: 30 December 2010).

World Health Organization (2010b). 'Electromagnetic Fields', available at http://www.who.int/peh-emf/en/ (accessed: 25 November 2010).

Appendix I. Criteria used to evaluate scientific literature

Part in the article	Criteria	Description of the criteria
General	Author(s)	Who are the authors? What is their background (education, job, etc.), specialization, publication history? Does their background tell us something about possible objectives or biases?
	Type of information	Book, paper, website, etc.
	Year of publication	Is this current knowledge?
	Where is it published	Is it published on-line, or (also) on paper? Is it peer-reviewed? What kind of magazine/journal is it? What is the background of the journal?
Introduction	Aim/purpose	Is the aim and/or purpose of the article clear? Does this match with the rest of the article?
	Relevance of research	Why is this research important?
Material and methods	Blind/double blind?	Was the research performed blind or double blind?
	Randomized?	Are e.g. Bees, or treatments, chosen randomly?
	Influencing results	Could the results be influenced by for example sampling protocol, measurements, observators?
	Accuracy	Are the methods accurate enough to give relevant and usable results?
	Number of observations/sample size/repetition.	Was the experiment repeated, was the sample size big enough to draw sound conclusions and apply statistics?
	Justification of measurements	Why did they chose these measurements, can they answer their question and are they appropriate?

	Statistics	Will they use statistics? Are the appropriate statistics applied?
Results	Significant results?	Do they show significant results?
	Quality of graphs/tables	Are the graphs and tables informative, do they look professional and is the appropriate type of displaying chosen?
	Correctness	Are the presented facts correct?
	How detailed are the results?	Are the results detailed enough (e.g. significance levels mentioned)
	Completeness	Are the results complete? Are there enough results to draw conclusions from?
Discussion	Critical?	Are the authors critical on their own findings? Is this criticism correct?
	Appropriate discussion?	Are the results compared to other studies? Do the authors give recommendations for further research?
Conclusion	Appropriate conclusions?	On basis of the results, can these conclusions be made? Does the conclusion answers the research questions?
References	Correct use of references?	Are statements made on the basis of references? Are the references made in a correct way (following the rules for referencing)? Any plagiarism?
	Reliable?	Are the references reliable (e.g. based on the points mentioned in this table)? Are the references diverse?
	Do references support research?	Are the references relevant?
Other	Objectivity?	Can we conclude that this information is objective?

Sponsorship?	Is the research/website sponsored by a company that is objective?
Organization of information	Is the information organized in a correct, readable and appropriate way? Are topics mentioned in the correct part?
Consistent (design, topics)	Is the information consistent in design, is the information in the introduction relevant for the rest of the article?
Up-to-date?	Is the knowledge in this piece of information still valid and accepted?

Appendix II. Glossary

Apoptosis:	programmed cell death.
Bee queen:	a mated adult female bee, the queens are developed from larvae selected by worker bees and specially fed in order to become sexually mature.
Brood:	developing young honeybees in cells: eggs, larvae and pupae
Cryptochromes:	group of blue light photoreceptors from plants and animals. They are involved in the circadian rhythm of plants and animals and for some species they are also involved in sensing of the magnetic field.
Cytoskeleton:	cellular skeleton in the cytoplasm, is made out of proteins.
Drone:	male honeybee, developed from eggs that have not been fertilized.
Ferromagnetic material:	material which is displaying ferromagnetism, attraction to magnets, such as various forms of iron, steel, cobalt and nickel.
Gonad:	glands producing hormones which, prior to birth, cause the development of gender-specific traits, and producing sexual cells (eggs, spermatozoa).
Holometabolism:	a complete metamorphosis.
Inclination compass:	an instrument to determine the angle of the Earth's magnetic field in the point of view to the horizontal plane.
Ionizing radiation:	consists of particles or electromagnetic waves which carry enough energy to detach electrons from atoms or molecules.
Magnetoreception:	is the ability to sense the magnetic field for the perception of direction, altitude or location.
Mechanosensory system:	system which enables sensing of mechanic stimuli, such as pressure.
Modulation:	waves amplitude, frequency or phase is changed in order to transmit information.
Non-ionizing radiation:	type of electromagnetic radiation, which has not enough energy per quantum to ionize atoms or molecules, but has enough energy for

excitation.

Non thermal effect: any effect that is not due to heating

Nurse bee: a worker bee that feeds the larvae and young worker bees with royal jelly.

Oscillate: fluctuate, swing.

Pheromone: is a secreted or excreted chemical factor that generates a social response in members of the same species.

Photoreceptors: specialized type of neuron in the eyes of the retina that is able to convert light into electrical signals.

Polarization (light): the orientation of the vibration of light waves as they travel through the sky. Polarization changes the light from travelling in an unordered or mixed way, into travelling in a well-defined way.

Radical pair reaction (navigation in birds):
a magnetically sensitive chemical reaction.

Specific Absorbance Rate (SAR): a measure for the rate at which energy is absorbed by a body when it is exposed to radio frequency electromagnetic fields.

Torque: rotation force around a pivot or axis

Trophocyte: a lower type of cell which provides nutrition to a higher type of cell of a tissue.

Worker bee: female bee that lacks the full reproductive capacity that the queen has.