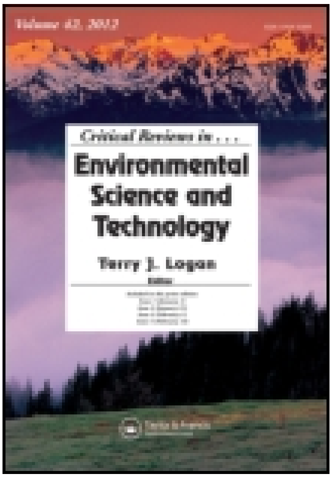

Critical Reviews in Environmental Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/best20

Environmental Impact of Radiofrequency Fields from Mobile Phone Base Stations

Luc Verschaeve[ab]

[a] Scientific Institute of Public Health, O.D. Public Health and Surveillance, Brussels, Belgium

[b] Department of Biomedical Sciences, University of Antwerp, Antwerp, Belgium

Accepted author version posted online: 02 Sep 2013.Published online: 14 May 2014.

To cite this article: Luc Verschaeve (2014) Environmental Impact of Radiofrequency Fields from Mobile Phone Base Stations, Critical Reviews in Environmental Science and Technology, 44:12, 1313-1369, DOI: 10.1080/10643389.2013.781935

To link to this article: http://dx.doi.org/10.1080/10643389.2013.781935

Critical Reviews in Environmental Science and Technology, 44:1313–1369, 2014

ISSN: 1064-3389 print / 1547-6537 online
DOI: 10.1080/10643389.2013.781935

Environmental Impact of Radiofrequency Fields from Mobile Phone Base Stations

LUC VERSCHAEVE[1,2]
[1]*Scientific Institute of Public Health, O.D. Public Health and Surveillance, Brussels, Belgium*
[2]*Department of Biomedical Sciences, University of Antwerp, Antwerp, Belgium*

This review examines the potential environmental impact of radiofrequency (RF) fields emitted by mobile phone base station antennas and other sources of RF radiation. Overall, many alarming investigations were found but most are characterised by severe methodological shortcomings. For this reason these studies do not provide any evidence that observed biological effects are associated with exposure to the electromagnetic fields. So far, the studies do not prove that environmental exposures to mobile phone base station radiation (and other environmental RF exposures) are harmful to wildlife.

KEY WORDS: biological effect, environment, mobile phone, radiofrequency radiation

I. INTRODUCTION

The large-scale use of electrical technologies has led to widespread environmental exposures to electromagnetic fields (EMF) over wide frequency ranges. Especially power lines (extremely low frequencies, ELF), high-power broadcast transmitters, radars and mobile phone base station antennas (radiofrequencies, RF) may produce moderate to strong fields in their vicinity. EMFs from power lines and radiation from antennas for wireless communication are often suspected to be responsible of adverse health effects. Although most of the scientific papers do not show such effects, there are a number of alarming studies that require a careful examination. Not all of these can be dismissed on basis of experimental errors, too small sample sizes, dosimetric uncertainties and other shortcomings. The International Agency for

Address correspondence to Luc Verschaeve, Scientific Institute of Public Health, O.D. Public Health and Surveillance, Brussels, Belgium. E-mail: luc.verschaeve@wiv-isp.be

Research on Cancer (IARC) therefore classified ELF-magnetic fields, as well as RF–EMF (including those from the mobile phone technologies) into group 2B which contains agents that are 'possibly carcinogenic to humans' (IARC, 2002, 2012). This classification was based on a number of epidemiological and laboratory investigations that have provided limited evidence for carcinogenic effects. In this paper, we review the studies that were particularly devoted to environmental effects of RF fields from mobile phone base stations and other RF emitting sources. Attention is thus paid to *in situ* effects on wildlife, including plants. This means that the present report does not give an exhaustive overview of laboratory investigations although we yet considered some particular laboratory studies when they were conducted in conditions that may be considered of relevance to the natural environment. Reviews from *in vivo* laboratory investigations and human studies can be found elsewhere (e.g. Juutilainen et al., 2009, 2011; van Rongen et al., 2009; Verschaeve et al., 2010).

This overview should be seen in the framework of the European efforts and EU-wide network of nature protection that was established under the 1992 habitat directive. The aim of the network is to assure the long-term survival of Europe's most valuable and threatened species and habitats. Installation and maintenance of base station antennas in such habitats should be subject to restrictions as they may, according to the habitat and particular situation, be responsible for important disturbances of, for example, endangered species. Besides these, effects from exposure to the RF radiation on wildlife should also be assessed. The present paper gives a critical review of investigations that were conducted on animals and plants following exposure to radiation from mobile phone antennas. Reviews should normally only take into consideration literature published in scientific peer-reviewed journals to guarantee the selection of articles of sufficient quality, i.e., free from methodological deficiencies (Repacholi and Cardis, 1997). This paper yet considers a number of studies that were not peer reviewed or not published in high quality scientific journals and do not satisfy the quality criteria adopted by some international expert groups (e.g. SCENIHR, 2012). This is because they are often cited and therefore yet need to be part of a critical evaluation and be put into perspective. On the other hand we probably have missed some studies, either by not knowing them, or in only a few cases, because these papers did not provide any useful information.

II. THERMAL AND NON-THERMAL EFFECTS OF RF RADIATION: DOSIMETRIC CONSIDERATIONS

When an organism is exposed to EMFs, it absorbs energy. The amount of absorbed energy depends on many factors, amongst them the frequency of the radiation, the power density, the electrical properties of the exposed tissues, the orientation and possible attenuation of the fields, etc. Exposures to low-frequency EMF result in such small energy absorption that thermal effects (increased body temperature) are usually inexistent. Thermal effects due to substantial energy absorption are more likely at frequencies above 100 kHz. Radiofrequency electromagnetic fields (100 kHz–300 GHz) can therefore produce thermal effects (temperature increases above 1°C) provided absorbed power is sufficiently high. Thermal effects are well known and may account for virtually all possible health effects (Verschaeve, 1995). The tissues temperature may increase at a specific absorption rate (SAR) above approximately 2 W/kg and could have irreversible consequences if it exceeds 4 W/kg for a certain time.

This is the reason why the SAR remains the basis for hazard identification. It gives the conversion from energy into heat and is expressed in Watt per kilogramme (W/kg). It depends on the internal electromagnetic field of the tissue according to the following formula:

$$\mathrm{SAR} = i^2/\sigma\rho = \sigma E^2/\rho,$$

where i is the current density in A/m^2, ρ the specific mass in kg/m^3, σ the electric conductivity in Siemens per meter (S/m), and E the electric field in volt per meter (V/m).

There are publications in the literature that suggest that biological effects can also occur at non-thermal exposure levels, but so far there is no general consensus about their impact on health. Examples are alterations of calcium ion mobility in tissue cells. However, these effects are not sufficiently established to provide a basis for restricting human exposure. Most scientists therefore still consider that such effects have no or at least no proven impact on health (Kwan-Hoong, 2003; Verschaeve, 2012). Possible specific effects of amplitude-modulated radiofrequency fields were also suggested. This hypothesis has been widely discussed and is still debated in the scientific literature (Juutilainen et al., 2011; Kowalczuk et al., 2010; Balzano & Sheppard, 2012).

It is well known that the exposure levels in the vicinity of mobile phone base station antennas are very different from the exposure that a mobile phone user will receive. Accessing the area in front of mobile phone base station antennas and close to it is normally impossible, except for the technicians during maintenance operations. The places where the public can access are always at least at several metres from the radiations source. Therefore, living close to mobile phone base station antennas means that the exposure duration is long, but only at a low intensity. On-site measurements reveal that the electric field in places where the public can stay for a rather long period is nearly always lower than 2 V/m. Mobile phone users are exposed to much higher intensities, but the duration of exposure barely exceeds several tens of minutes per day. Depending on the mobile phone used, the corresponding SAR (maximum local values found in any 1 g of tissue in the user's head) ranges between 0.3 and 1.5 W/kg. The highest SARs are found with old mobile phone types and the more recent models feature the lowest values. It must be mentioned that these figures correspond to the worst case, i.e. when the mobile phone is used in poor radio coverage conditions. Real exposure is usually much lower as the power control mechanism automatically adjusts mobile phone power to a level just sufficient to keep an acceptable communication quality. In real situations, the actual SAR is therefore usually significantly lower than the value indicated on the manufacturer data sheet. Furthermore, the spatial variation of SAR is high, and the average SAR in, e.g., the whole brain is *much* lower than the local maximum values.

Whichever the SAR of the mobile phone, the exposure of the head of the user is high in comparison with the (all body) exposure produced by mobile phone base stations at locations that are accessible to the public or to animals. Although animals may of course more easily access areas close to antennas (on masts, water towers or inside churches), we yet may assume that most influences from RF radiation in environmental situations, if any, may be ascribed to non-thermal effects as animals or plants are usually also sufficiently distant from the antennas.

When an experiment has shown an effect (even if it is not yet confirmed by replications or additional investigations), it is important to be able to decide whether the conditions in which the experiment was carried out (exposure level and duration) are relevant to environmental situations. The fact that the exposures are expressed in different units (electric field component in V/m, power density in W/m^2 and SAR in W/kg and with the multiples or submultiples of these units) means that it is very difficult for people who are not experts in the field to locate the level at which an effect can possibly appear.

Table 1 gives an indication of the exposure levels one may encounter in typical situations, namely:

- Exposure levels that the general population or animals may be faced with when living near mobile phone base stations,
- Exposures of the head region of a mobile phone user, and
- The temperature increase threshold.

Table 1 should help the reader to decide for which typical situation the result of an experiment is relevant or not. We insist on the fact that the data in the table are only indicative. They should not be understood as clear and fixed limits.

TABLE 1. Indication of RF exposure levels in different situations

Situations	Electric field (1) (in V/m)	Power density (2) (in W/m^2)	(in mW/cm^2)	SAR at 900 MHz (3) (W/kg)
Mobile phone base station neighbourhood	<1 to 2 V/m (4)	$<3 \times 10^{-3}$ to 10×10^{-3}	<0.3 to 1	$<4 \times 10^{-5}$ to 2×10^{-4}
Against the head of a GSM mobile phone user	80–100 V/m (RMS value) (5)	17–27 assuming far field conditions (6)	1.7–2.7 assuming far field conditions (6)	0.3–0.5 and up to 1.5 with old types
Temperature increase threshold (≅1 °C)	150–300 for 30 min	60–240 for 30 min	6–24 for 30 min	1–4 for 30 min (7)

(1) It should be noted that according to ICNIRP, a reference level of ~41 V/m guarantees a SAR < 0.08 W/kg at 900 MHz (ICNIRP, 1998).

(2) In the far field, the power density S (in W/m^2) is given by the formula $S = E^2/Z$, where E is the electric field intensity (in V/m) and Z the impedance of the medium (in Ω).

(3) The SAR is proportional to the square of the electric field intensity and is impacted by various parameters such as frequency, field polarisation, etc. The SAR given in the table corresponds to a frequency in the 900 MHz band. It has been inferred on the fact that, according to the ICNIRP recommendations, a reference level of 41 V/m guarantees a SAR < 0.08 W/kg at 900 MHz (ICNIRP, 1998, 2009).

(4) Near mobile phone base stations where the general population or animals can get access exposure levels are usually less than 1 or 2 V/m.

(5) The radiations generated by GSM mobile phones are present during a time slot (577 μs duration), which is repeated every 4.6 ms. The electric field intensity specified in the table correspond to the root mean squared value (RMS value).

(6) The formula which gives the power density $S = E^2/Z$ is only applicable in the far field. Using a mobile phone, this condition is not met. Therefore, the power density against the head cannot be calculated with the given formula, but it also cannot be measured with a classical field meter. Power densities mentioned here are therefore only indicative.

(7) In the ICNIRP recommendations (ICNIRP, 1998, p. 24), it is stated that: "Available experimental evidence indicates that the exposure of resting humans for approximately 30 minutes to EMF producing a whole-body SAR of between 1 and 4 W/kg results in a body temperature increase of less than 1°C". This shows the impact of the exposure duration. The specific (energy) absorption (SA) is equal to the SAR multiplied by the time and is expressed in J/kg. In the above observation, the SA ranges between 1,800 and 7,200 J/kg. If it is assumed that the effect of the thermoregulatory system and energy exchange with the medium are negligible, it can be concluded that an energy absorption in the same range for a few minutes should produce the same temperature increase. This involves that a 6-min exposure to a SAR between 5 and 20 W/kg should also result in a body temperature increase of less than 1°C.

III. A LITERATURE REVIEW OF PUBLISHED DATA

A. Emphasis on "Positive Studies"

The purpose of the present literature review was to determine whether radiation from base station antennas is able to harm, disturb or influence the behaviour of organisms in their natural habitat. We therefore have performed a critical analysis of the data taking particularly attention to positive (alarming) data. It was considered important to perform an in-depth analysis of especially positive findings and to estimate their relevance and correctness paying attention to the methodology and dosimetry. This allows, for example, verification of whether an alleged non-thermal effect was indeed non-thermal in nature. Most of the investigations on the environmental impact of RF radiation from base stations were performed in real-environmental situations, but even then incorrect dosimetry may lead to incorrect or at least unproven associations. As we focus on reported *effects*, positive findings were especially analysed. This does not mean that we are less critical with respect to reported *negative* findings.

B. Effects on Insects

There were several studies on insects which were essentially devoted to effects on reproduction and development. They are reviewed below. Other studies (e.g. Vácha et al., 2009) were devoted to the perception of the geomagnetic field and the influence of weak RF fields upon this. However, these fields are not relevant with respect to alleged effects of mobile phone base station antennas and radar stations and will therefore not be discussed in this paper.

1. Bees

The term *colony collapse disorder* (CCD) was first applied to a drastic rise in the number of disappearances of Western honey bee colonies in North America in late 2006 (van Engelsdorp et al., 2009). Honey bee colony losses were also observed in many European countries as well as elsewhere in the world (Haubrugge et al., 2006; Van Der Zee et al., 2012). This is an important problem because many agricultural crops worldwide are pollinated by bees. It is estimated that bees are responsible for some 80% of all insect pollinations (Free, 1993). Although large-scale losses are not new to the beekeeping industry and were reported since at least 1869, some hypotheses attempting to explain CCD or related phenomena are recent and clearly do not account for the earlier cases. Among the hypotheses, one concerns deleterious effects from RF radiation from mobile phone base stations. In his report on "destroying nature by electrosmog", Warnke (2009) mentioned a limited survey amongst beekeepers whose beehives were located within 300 m of a mobile radio antenna. In 37.5% of the cases, increased aggressiveness of the bees was observed compared to the time before the transmitters were in operation, 25% of the beekeepers observed a greater tendency to swarm and 65% confirmed inexplicable collapsing of colonies. The results of this survey were seen as indicative of RF radiation effects on bee behaviour and CCD. The hypothesis that CCD may be due to RF from mobile phone antennas is especially circulating in non-scientific publications on the Internet and explained, for example, by observations indicating that bees use the geomagnetic field for their orientation and respond to very small magnetic field changes (Frankel, 1984; Walker and Bitterman, 1989; Kirschvink and Walker, 1995; Frier et al., 1996; Kirschvink et al., 1997), by effects from power lines (Carstensen, 1987) and the presence of electrostatic charge on bees which adds in the adherence of pollen. The fact that honeybees can be trained to respond to very small changes in geomagnetic field intensity (Walker and Bitterman, 1989) also shows their sensitivity to EMF. According to some studies, effects related to power lines were apparently due to electrical shocks that the bees receive when they contact surfaces in the hives (Carstensen, 1987; Bindokas et al., 1988) rather than to the influence of the EMF as such. Furthermore, the frequency of these fields is much lower and their properties so different that such results cannot be extrapolated to the RF radiations. For example, the electric and magnetic fields are separate phenomena in case of extreme low frequency (ELF) fields but they are coupled together as radiation when radiofrequency fields are concerned. ELF fields (as from power lines) can induce currents in the body but unlike RF fields they cannot cause heating in the body. Biological effects can therefore be very different (SCENIHR, 2009). So far evidence that the compass ability of the honeybees can suffer from radiofrequency fields is still missing (Válková and Vácha, 2012) and evidence for adverse effects from mobile phone radiation is extremely poor. Indeed, there were only a few scientific publications related to effects from mobile phone radiations and comparable frequencies on bees but, unfortunately, they are all characterized by severe shortcomings which are sometimes mentioned by the authors themselves. A first of these studies concerned orientation, behaviour and memory functions in bees that were exposed for 30 min to 2450 MHz (3–500 W/m^2) continuous microwaves. There were no indications of an effect from the microwaves (Gary and Westerdahl, 1981).

In another investigation, Kimmel et al. (2007) used standard digital enhanced cordless telecommunications (DECT) telephones at 1900 MHz to expose a number of beehives (continuous exposure, 2.5 mW average transmitting power), while others were unexposed controls. DECT telephones were placed under the hives. Bees were taken away from the hives and set free simultaneously at some 800 m from the hives. Significant differences in returning to the hives were observed. Out of 25 bees, 16 and 17 bees returned to their non-exposed hives within 28 and 32 min, respectively, whereas only 6 bees returned after 38 min in one of the exposed hives and none returned in the other one. The same researchers previously described an experiment carried out by students in which the building behaviour of the bees within the beehive, its weight and the bees' returning behaviour were investigated. While the weight of the honeycombs was similar in the beginning, the average total weight of the honeycombs, which were built by non-exposed bees, was higher than that of honeycombs built by exposed bees. Also the number of returning bees of the non-exposed honey bees was higher, and the returning time of the few returning exposed honey bees was distinctly longer (Harst et al., 2006). These studies were considered preliminary, and the authors themselves indicated that the exposure could not be well controlled, and the influence of RF exposure could not be proven. They also reported technical problems with the counting device (a bee scan unit) and mentioned that some data could not be taken into account.

The performance of honeybees exposed or unexposed to cell phone radiation (GSM, 900 MHz) was also investigated by Sharma and Kumar (2010). This study attracted much media attention as it reported a significant decline in colony strength and in the egg laying rate of the queen in exposed bees compared to the controls. This was however a very small study with two test colonies, one control and one unpowered-cell-phone control. It does not allow drawing any conclusion due to small sample and many shortcomings. The authors for example claim (page 1377) that the bees, became "quiet and still or confused during exposure, as if unable to decide what to do." This is not a scientific observation. The authors furthermore state that "at the end of the experiment there was neither honey, nor pollen or brood and bees in the colony results in complete loss of the colony." Yet in the results table, there are measurements of honey stores, pollen stores, brood size and bee strength, and all of those measurements were nonzero. The authors stressed that fewer bees left the hive during cell phone exposure, that fewer bees returned to the hive per minute, and that fewer bees returned with pollen per minute. This gives the impression that many things went wrong, but as a matter of fact they all are the same. If fewer bees leave, fewer bees will return and obviously there will be fewer bees with pollen.

The author's claimed that their study suggests that colony collapse does occur as a result of exposure to cell phone radiations. This is not true. Their study only suggests that putting a cell phone in a hive annoys the bees and may hurt the colony. The study did not report what happened after termination of the experiment and did not use any statistics, presumably due to small sample sizes.

Other important deficiencies come from the characterisation of the electromagnetic environment. The location of the hive was not described nor any indication of the presence or absence of possible confounders, e.g., presence or absence of base station antennas or other sources of electromagnetic radiation or pollution. Exposure to the radiofrequency radiation was realised by placing two cell phones in call mode on the two side walls of the bee hive. In these conditions it is virtually impossible to obtain average electric field values as indicated by the authors (56.8 V/m). This simply cannot be obtained in the given experimental conditions. Finally it is not correct to express exposure as power densities in near field situations. For a GSM-900 handset the distance should at least be 33 cm. If this is not the case only a rough estimate of the field can be made.

Kumar et al. (2011) reported about a biochemical investigation on bees that were housed inside a specially designed wooden box and exposed to the radiation of mobile phones in listen-talk mode for 10 up to 40 min.

These investigators reported a reduced motor activity of the worker bees on the comb, followed by en masse migration and movement toward the "talk mode cell phone". The initial quiet period was characterised by rise in concentration in hemolymph of biomolecules including proteins, carbohydrates and lipids. At a later stage of exposure, there was a slight decline in the concentration of biomolecules which was explained by an adaptation to the stimulus. This study did not provide details of the experimental set-up, and no field measurements were reported. It is therefore not possible to make sound conclusions from this investigation.

Another investigation was simultaneously published in two different journals (Sanudeen Sahib, 2011a, 2011b). In this study, bee colonies were provided with 900 MHz mobile phones in working conditions and exposure to RF radiation described as "for ten minutes for a short period of ten days". The power density was measured with a RF power density meter but no further indications were given (not even on the measured field values). According to this study, the worker bees never returned to their hives, and the queens in the test colonies produced fewer eggs per day compared to the controls. Due to complete absence of reliable experimental data, it is impossible to take this study into account. Actually, this paper was a pamphlet rather than a reliable investigation which was full of unconfirmed statements, omissions and errors. It was, for example, stated that exposure of queen bees to cell phone radiation stimulated the production of only drones, but reference was made to a paper involving exposure to X-rays and not RF radiation.

Still another investigation reported behavioural disturbances in bees as a result of RF radiation from two transmitting GSM handsets placed in the same hive. The noise produced by bees was recorded and analysed. Audiograms and spectrograms showed that bees produce in the presence of the radiation a so-called *worker piping signal*, which is normally produced only before swarming or when severe disturbance of the hives occur (Favre, 2011). It should be noted that experimental conditions did not coincide with "normal" exposure conditions, for example, where hives are nearby a base station antenna. According to the author, the piping signal was regularly observed about 25–40 min after the offset of the mobile phone communication. Although it seems that the experimental conditions were well controlled, the rather long response time could indicate that the piping signal was caused by another phenomenon that the RF field. For example, the electronic components of the two mobile phones which dissipate about 1 W in a closed space could likely heat the air contained in the hive, especially in the vicinity of the mobile phones. Apparently no temperature measurements were performed in the hives. It should be also stressed that no bees died in the experiment and that all the bees eventually returned to normal. The authors nevertheless demonstrated that honeybees are sensitive to pulsed electromagnetic fields generated by mobile phone radiation and that under the given experimental conditions observable changes in the behaviour of the bees are not artificial. The authors never claimed that this is why bees die or that their experiment demonstrated that mobile phone radiation is the cause of CCD. The authors are well aware that their data do not allow such far-reaching conclusions.

Mixson et al. (2009) reported absence of any effect in a series of experiments on the effects of radiation emitted by GSM cellular phones (1900 MHz; $1.41 \pm 0.483\ \mu W/cm^2$) on the behaviour of harnessed and free-flying bees of three different subspecies. Relative to control animals, exposure did not influence proboscis extension or feeding, and no influence was seen on return to target or aggression. As for previous experiment, exposure was not well characterised.

Effects were thus observed in some experiments, but most of them were characterised by severe shortcomings. It is therefore impossible to draw any firm conclusion.

Just as in other countries, beekeepers in the United Kingdom encountered problems in recent years, but the year 2010 was again a "good year". This is seen by some as a solid argument to clear mobile phone radiation from any suspicion regarding its role in CCD (Douglas, 2010). It is sometimes also claimed that CCD cannot be due to radiation from mobile phone base stations as most cases in the United States are found in rural environments with bad mobile phone network coverage (but further explanation on what this means is lacking). Mobile phones are in use for some 20 years now, and worldwide large-scale colony losses are more recent. This is also put forward as an argument against mobile phone radiation as a causative factor. But it again does not prove anything. It may also be argued that the problems became manifest only after the introduction of the third-generation mobile phone system and the increase in the number of mobile phone masts. Present research does not allow a final conclusion. According to a report of the CCD working group, CCD is most probably not due to a single cause but to the combined action of different agents or influences (CCD Working Group, 2010). The working group also published another study in which they concluded that bees from CCD colonies are more infected by pathogens than this is the case in control animals (van Engelsdorp et al., 2009; Ratnieks and Carreck, 2010).

Infections are thought to be the main reason for CCD but as they can be due to a decreased immunity the role of mobile phones can theoretically not yet be ruled out. Yet, other explanations for (honey) bee decline are more likely. These are, for example, (a combination of):

(i) Nutritional stress and dryness which may be responsible for loss of plant diversity (CCD Working Group, 2006; Alaux et al., 2010) and resulting deficiencies that may in turn promote the development of parasitic mites (Sharpe and Heyden, 2010).

(ii) Parasitic mites (*varroa)* and viruses (Minkel, 2007; Higes et al., 2009; Guzmán-Novoa et al., 2010; Singh et al., 2010), although it is realised that not all cases of CCD can be ascribed to these (Anonymous, 2009).
(iii) Pesticides, as, for example, *neonicotinoid imidacloprid*. This is a nerve poison which impairs coordination (Johnson et al., 2010).
(iv) Antibiotics and miticides (Oldroyd, 2007).
(v) Genetically modified agricultural products (Berger, 2007; Malone and Pham-Delègue, 2001). Some produce, for example, Bt toxin (an insecticide) which may have effects on bee populations. Yet, this is not well documented and verified (Marvier et al., 2007; Duan et al., 2008).
(vi) Climate change responsible for a change in flowering period of certain plants (Berger, 2007).
(vii) Telomere shortening of chromosomes as a result of inbred provoking premature ageing (Stindl and Stindl, 2010).

In conclusion, although some studies suggest an influence of mobile phone radiation on the occurrence of CCD (also called *Honey Bee Depopulation Syndrome, HBDS*) and related effects, there is no solid scientific basis for this. A combination of different other causes may provide a more plausible explanation for this phenomenon.

2. Drosophila

All investigations on *Drosophila* were performed in laboratory conditions. We will yet describe them as these are often taken into consideration in the debate on possible environmental effects of mobile phone radiation. Many of the studies concerning mobile phones and *Drosophila* were conducted by the same research group (Panagopoulos et al., 2004, 2007 2010; Panagopoulos and Margaritis, 2008; Panagopoulos, 2012; Chavdoula et al., 2010). They, for example, investigated effects of pulsed GSM-900 radiation and concluded from their study that the reproductive capacity of male as well as female flies is affected. According to the authors, GSM-radiation interferes with the development of the gonads (Panagopoulos et al., 2004, 2012; Chavdoula et al., 2010). They also confirmed this for 1,800 MHz radiation. The effects were explained as the result of DNA fragmentation in the gonads (Panagopoulos et al., 2007, 2010; Panagopoulos and Margaritis, 2008; Chavdoula et al., 2010).

The experiments of Panagopoulos et al. thus gave alarming results. In most of the experiments, the insects were put in groups of 10 in standard laboratory 50 mL cylindrical glass vials (tubes), with 2.5 cm diameter and 10 cm height. The glass vials were placed in contact and parallel to the external antenna of a commercially available 900 MHz mobile phone. The insects were exposed for 6 min per day during the first days of their adult lives. According to the authors mobile phones were used that do not cause SAR values higher than 1 W/kg.

The authors stated that the temperature during exposures was monitored within the vials containing the insects and that "no temperature increases during the GSM exposures were recorded within the vials with the insects or within the mass of the food". It is not clear how precise and valid the temperature mesurements were.

The RF EM field and the ELF electric and magnetic field intensities were measured. Unfortunately, the method is inappropriate, and the exposure values are wrong as described below.

Concerning the RF EM field, it is well known that the region close to an antenna is the reactive near field zone which typically extends to a distance equal to one-third of the wavelength (i.e. about 10 cm at 900 MHz) with most mobile phone handset antenna types. It is stated that the measurements at 900 MHz were performed with an RF radiation survey meter, NARDA 8718, and the measured intensity is given in mW/cm^2.

The NARDA 8718 RF radiation survey meter is an instrument which should be used with a probe of the 8700D series, each model being dedicated to a certain frequency band and measurement range. The paper does not mention which probe was used. However, none of the probes available from the manufacturer for the NARDA 8718 is able to provide any estimate of the power density (in W/m^2 or submultiples) in the reactive near field zone. In the NARDA technical literature, it is stated that "the majority of the 8700D series probes have four inch (10 cm) diameter heads. The minimum measurement distance for these probes is about 4 inch (10 cm) from the outside surface of the probe. Measurements made at closer distances can result in inaccurate readings due to capacitive coupling. The Models 8721D, 8723D, 8725D and 8783D have two-inch (5 cm) diameter heads that can be used as close as 2 inch (5 cm) from the source to the outside of the probe." It is therefore clear that placing the probe in contact with the mobile phone antenna is a wrong procedure.

In addition, the exposure level is expressed by the power density. It is also well known that this parameter is inappropriate to measure the field strength in the reactive near field zone where, in principle, the electric and magnetic field components have to be measured separately. As a consequence, the power densities mentioned in Panagopoulos et al. (2004, 2007 2010), Panagopoulos and Margaritis (2008), Panagopoulos (2012) and Chavdoula et al. (2010) are not correct.

The measurement of the ELF electric and magnetic field components is not correct either. It is stated that: "... we measured in the same way the mean electric and magnetic field intensities at the extremely low frequency (ELF) range, with the field-meter Holaday HI-3604 ELF Survey Meter. The measured values for modulated fields, excluding the ambient electric and magnetic fields of 50 Hz, were 6.05 ± 1.62 V/m electric field intensity and 0.10 ± 0.06 mG magnetic field intensity .... These ELF components of the GSM field are basically due to the pulse repetition frequency of 217 Hz ... ."

It is established that the ELF magnetic field component (at 217 Hz) is due to the mobile phone battery current and not to the amplitude modulation of the RF carrier. The Holaday HI-3604 meter is an instrument designed to measure low-frequency electric and magnetic fields produced by 50/60 Hz power lines, line-powered equipment and appliances. Its sensor (≈15 cm diameter loop) is too large to measure accurately the ELF components produced by a small source such as a mobile phone. In addition, the Holaday HI-3604 meter is a low-frequency wideband meter, the measurement of which is impacted by the ambient electric and magnetic fields of the 50 Hz network. The authors do not explain how the 50 Hz contribution has been subtracted. All these considerations do not invalidate the biological observations on Drosophila but it is difficult to ascribe the real cause of the findings to 'normal' exposures to mobile phone radiation.

Another investigation, conducted by Weisbrot et al. (2003), was devoted to 900 and 1,900 MHz mobile phone signals at a SAR of approximately 1.4 W/kg. The purpose was to study the effects of a RF signal produced by a GSM multiband mobile phone on *Drosophila melanogaster*, during the 10-day developmental period from egg laying through pupation. Exposure conditions imply that exposure was not only to RF fields but also to ELF fields. So, ELF fields may also contribute to (some of) the results. No temperature increase was observed which means that the exposure can be assumed to be non-thermal. This non-thermal irradiation from the GSM mobile phone increased numbers of offspring, elevated levels of the stress protein *hsp*70, increased serum response element DNA-binding and induced the phosphorylation of the nuclear transcription factor, ELK-1. These effects on cellular function were apparently reflected in an increased number of adults when growth and development occur during cell phone exposure. It was assumed that this was the result of increased ovulation and/or increased cell divisions. This is in contrast with the observed decreased reproductive capacity as reported by, for example, the team of Panagopoulos (e.g. Panagopoulos and Margaritis, 2008).

Other microwave frequencies were also investigated. No differences were found in the transition percentages from larvae to pupae and from pupae to adults when larvae, placed in glass tubes (2.5 × 7.5 cm), were exposed to 10 GHz fields (3, 4 and 5 hr continuously or discontinuously, 3 hr exposure + 30 min interval + 3 hr exposure) at a power density of 15.6 mW/m^2 (measured outside the glass tube). As the mean pupation time was delayed linearly with an increasing EMF exposure period and discontinuous exposure resulted in less offspring compared to non-exposed controls, it was concluded yet that 10 GHz EMF can cause developmental delay and reduced fertility in *D. melanogaster* (Atli and Unlü, 2006). Although this is not mentioned by the authors, the power density to which the larvae were actually exposed in the glass tube is likely rather low (much less than the

TABLE 2. Investigations on RF-radiation induced genetic damage in *Drosophila*

Exposure conditions	Study	Results	References
146.34 MHz (120 W) 29.00 MHz (300 W) (12 hr)	Sex-linked recessive lethals	No effect	Mittler (1976)
98.5 MHz (0.3 V/m) 32 weeks	Sex-linked recessive lethals	No effect	Mittler (1977)
2450 MHz SAR: 100 W/kg (6 hr)	Somatic mutations (eye pigmentation)	No effect	Hamnerius et al. (1979)
2.45 GHz (CW) 3.10 GHz (PW) 27.12 MHz (E or H field) (6 hr)	Somatic mutations (eye pigmentation)	No effect	Hamnerius et al. (1985)
2375 MHz (CW) 15 W/cm^2 (60 min/day) 20 W/cm^2 (10 min/day) 25 W/cm^2 (5 min/day) (5 days)	Sex-linked recessive lethals	No effect	Marec et al. (1985)

15.6 mW/m^2 measured outside the tube) due to the high attenuation of the glass at 10 GHz.

Above investigations thus showed either a decreased or increased reproductive capacity following RF mobile phone exposure. These results are therefore to a certain extent contradictory. It may also be stressed that older studies on genetic changes which may cause reproductive effects as suggested by the authors of previous investigations (Panagopoulos et al., 2007, 2008, 2010; Chavdoula et al., 2010) were all invariably negative (Table 2; see for example, Léonard et al. 1983; Verschaeve, 1995; IARC, 2012; WHO, 1993). Here, no obvious methodological or technical shortcomings were identified.

In one of these, male adult *D. melanogaster* flies were exposed to radio waves for 12 hr on the antenna of a 20 W transmitter at the frequency of 146.34 MHz and to 29 MHz produced by a 300 W transmitter (Mittler, 1976). The loss of X or Y chromosomes, non-disjunction and induction of sex-linked lethals were determined. No significant effects were seen. Chronic exposures to 98.5 MHz (0.3 V/m) were also investigated. Exposures for 32 weeks did not induce sex-linked recessive mutations (Mittler, 1977).

Other studies were devoted to somatic mutations involving eye pigmentation. Embryos were exposed in water for 6 hr to 2450 MHz continuous waves with an average SAR of 100 W/kg. No mutagenic effects were found (Hamnerius et al., 1979). Other 6 hr exposures (27.12 MHz E-fields, SAR <0.05 and 0.3 W/kg; 2.45 GHz EM-continuous waves, 110 W/kg, and 3.10 GHz EM-pulsed waves at 60 W/kg) also did not result in any significant differences compared to unexposed controls (Hamnerius et al., 1985).

A 5-day exposure to continuous 2,375 MHz fields, with field conditions described as 15 W/cm^2 (60 min/day), 20 W/cm^2 (10 min/day) and 25 W/cm^2 (5 min/day), also did not show any effect on *D. melanogaster* (Marec et al., 1985).

In conclusion, it can be said that, despite the relatively great number of investigations on *Drosophila*, no clear picture emerged. There were negative and positive studies, but many of them had (severe) shortcomings, especially with respect to the field measurements. Positive studies were furthermore also contradictory as a decreased reproductive outcome was seen in some investigations whereas an increased reproductive outcome was also reported.

3. Ants

In a recent study, Cammaerts et al. (2012) investigated visual and olfactory memory in ants. Several exposure periods were successively and discontinuously conducted. The intensity of the EMF was in the range that is usually encountered by living organisms nearby mobile phone base station antennas. The authors reported effects from 900 MHz waves at about 1 V/m (produced by patch antennas fed with an input power of 10 dBm) on foragers' ability in using olfactory and visual cues and revealed an impact on their physiology. Overall, this investigation was interesting and in line with, for example, some of the results found with bees. However, experimental shortcomings, inconsistencies and errors on the technical aspects prevent a full appreciation of the results.

The most severe shortcoming concerns the conditions in which the ants were exposed to RF radiations. The paper describes a test set-up in which the trays with the ants are placed on both sides of the RF generator. However, the RF generator which was used in the study (Rhode & Schwarz dual-channel SMATE200A vector signal generator) includes ventilators to dissipate the heat from the electronic components. These ventilators are located on the right side of the generator. The air flux enters and leaves the equipment through grids carried on the left and right sides of the equipment. These ventilators generate noise and, overall, air displacement on both sides of the RF generator and the set-up description shows that the ants were in the air flux at only a few tens of cm from the grids. As the marking pheromone produced by the ants contains volatile compounds, it cannot be excluded that the air flux has an impact on the experimental result. Clearly, the air flux and noise come in addition to the RF radiation, and the test is not only a test of RF radiation but also a test of the combined influence of three elements (RF radiation, air flux and noise).

Another important criticism concerns the fact that the authors does not seems to have performed any exposure measurement. The field intensity has not been checked with a field meter but was only calculated and it appears that this calculation is wrong. A solid knowledge of high frequency techniques is needed to make a correct connection between a 900 MHz RF generator and a patch antenna. It is an absolute requirement in such experimentations to check that the antenna actually radiates. Indeed, impedance mismatch, cable attenuation and defective connectors are frequent sources of troubles. If something is wrong, the antenna does not produce any radiation (or the intensity is lower than expected). One may wonder whether the exposure setup was operating correctly considering many errors regarding basic aspects that should be known by all radio engineers: For example, (1) the paper mentioned a power density of 7.95 × 10-5 mW/cm^2 but this should be 1.6 × 10-4 mW/cm^2, (2) dBm is a radiated power unit and not a power density unit, (3) a second generation GSM mobile phone (i.e. without the 3G functionalities for internet access) and which remains at the same place performs a "location update" every few hours and not every 30 sec as stated in the paper, (4) the authors also seem to confuse radiated power and power density which are totally different concepts.

C. Spiders

Cross spiders were exposed overnight (16 hr) to 9.6 GHz RF radiation during their web-building activity. Power densities were 10, 1 and 0.2 mW/cm^2, and the estimated SARs were 40, 4 and 0.4 mW/g. It was found that these conditions of RF radiation did not affect the web-spinning ability (Liddle et al., 1986).

D. Snails

A recent publication reported an investigation of the possible effects of mobile phone radiation on snail nociception; this is the neural processes of encoding and processing noxious stimuli. In this study, 29 land snails (*Helix pomatia*) were exposed to 1,900 MHz GSM signals at 48 mW/kg for 1 hr each. Sham controls consisted of another 29 snails. The experiment was conducted during the onset of summer, with all snails being well out of hibernation. Before and after GSM or sham exposure, the snails were subjected to thermal pain by being placed on a hot plate. Comparing the reaction pattern of each snail before and after exposure, the GSM-exposed snails were less sensitive to thermal pain as compared to sham controls indicating that RF exposure induces a significant analgesia (Nittby et al., 2012).

E. Birds

A review document prepared for the "United States Fish and Wildlife Service, Office of Migratory Bird Management" reports that there have been quite a lot of investigations, especially during the 1970–1980s, on bird collisions with communication towers. These studies, in addition to studies of tower kills at recently developed wind turbine sites, suggest that shorter towers do not kill as many birds as taller towers (no major mortality events have been reported at the shorter towers), although this conclusion should not be considered definitive. With respect to research on the influence of radio frequencies in the range of those emanating from towers on migrating birds, there is little research. The report however concluded that experts do believe that these waves are not likely to cause disruption of night migrating birds' orientation or navigation systems (Kerlinger, 2000).

Bruderer and Boldt (1994) also did not see an influence of a 7.5–21.8 MHz 150 kW radio transmitter on homing success and vanishing time of pigeons. There was apparently no disruption of the orientational system in test or control birds, and there was no deterioration in the test birds compared to the controls. There were indications yet that the pigeons could feel the EMF.

Other studies on bird's capacity to sense the geomagnetic field did show that birds may lose compass orientation already at low RF-intensities (Thalau et al., 2005; Ritz et al., 2009). These studies were performed on the European robin. As a matter of fact, the effect seen at very low RF field strengths was observed only at a resonance frequency based on Zeeman interaction. It was obviously a resonance phenomenon at a frequency (1315 MHz) far from mobile phone frequencies and therefore not relevant with respect to mobile phone base stations and radar.

Other investigations were devoted to RF radiation from mobile phone base stations and bird's behaviour and occurrence. White-throated sparrows (*Zonotrichia albicollis*) and dark-eyed juncos (*Junco hyemalis*) were, for example, exposed in captivity to microwaves in an outdoor microwave exposure facility. The animals were exposed to 2.45 GHz fields with power flux densities of 25 mW/cm^2 (20 and 200 min exposure), 100 mW/cm^2 (20 min) and 155 mW/cm^2 (7 and 10 min). Cognitive and behavioural endpoints were studied, i.e. dominance behaviour/hierarchy, aggression and avoidance. Although exposed birds maintained their position within a flock with one exception, some appeared to have a change in their level of aggression after irradiation. The authors therefore concluded that the microwaves may have subtle effects on the behaviour of the birds within a captive-flock dominance hierarchy. The effect nevertheless did not seem strong enough to alter the position of the birds within the hierarchy (Wasserman et al., 1984a). It is important to point out the very high exposure levels (power densities from 25 mW/cm^2 to 155 mW/cm^2 for 20 min and more), which are sufficient to produce a significant temperature increase.

The same authors also performed aversion/attraction experiments to determine whether birds (in this case, blue jays, *Cyanocitta cristata*) can perceive the presence of 2.45 GHz continuous wave microwave irradiation. Attraction or aversion to fields of 25 and 50 mW/cm^2 was investigated. Aversion to both power densities was observed as animals were twice more present in zones that were shielded from the microwaves (Wasserman et al., 1984b).

Once again, the exposure level is high and sufficient to produce temperature increase as suggested by the authors. This study is therefore also not relevant with respect to normal exposures to radiation from mobile phone base station antennas.

The influence of mobile phone radiation from base station antennas was investigated on White Stork (*Ciconia ciconia*) populations in the urban region of Valladolid (Spain). In this study, 60 nests were divided in two groups, based on the distance to mobile phone antennas (group 1: less than 200 m, group 2: more than 300 m). Measurements of RF fields resulted in average electric field values between 0.53 and 2.36 V/m with minima of 0 V/m (which is improbable) and maxima of 3.5 V/m. Visual observations of the nests revealed that the total productivity at 200 m from a base station antenna is 0.86 ± 0.16, whereas this was 1.6 ± 0.14 at more than 300 m ($p < .001$). Twelve nests were found without young (=40%) at 200 m compared to only one (=3.3%) at more than 300 m. The results thus seem to indicate that RF radiation from base station antennas results in decreased fertility of storks which is already evident at low, but continuous exposure levels (Balmori, 2005). Other laboratory investigations, for example on Japanese quail (Coturnix japonica) embryos (e.g., Byman et al., 1985; Gildersleeve et al., 1987; Hamrick and McRee, 1975; 1980; McRee et al., 1975, 1983; McRee and Hamrick, 1977) were different in nature. They found, for example, that hatchlings which were irradiated by microwaves as embryos had normal growth rates and no obvious developmental abnormalities (Byman et al., 1985), and that irradiation of quail embryos with low-level microwave radiation does not affect the reproductive capacity of the hatchlings or of progeny produced from quails irradiated during incubation (Gildersleeve et al., 1987). Other studies related to reproduction and embryogenesis in laboratory animals were furthermore also predominantly negative, unless thermal exposure levels were reached (e.g. Heynick and Merritt, 2003; Juutilainen, 2005; O'Connor, 1999; SCENIHR, 2009; Verschaeve and Maes, 1998; WHO, 1993). These laboratory investigations were of course very different from the investigation on stork nests as they, for example, concern other frequencies and signal modulations, and another biological endpoint (embryonic development compared to fertility). They yet justify suspicion because alleged effects on fertility, as suggested by the observations on storks, should at least also coincide with effects on some of the other endpoints (e.g., reproductive capacity) found in other studies. And this was not the case.

The investigation on stork nests was performed in an urban area and was therefore not subject to strict laboratory conditions. This means that there are most probably many confounders that may account for the results. Field measurements were conducted in the frequency band 1–3 GHz, which means that also other radiation sources were included. Of course, one may assume that mobile phone radiation contributed the most to the total radiation load. Exposure measurements were unfortunately not accurate. Indeed, the author stated that, due to inaccessibility, the measurements were not performed at the exact location of the nests. They were made by directing the probe of the field meter towards the antenna in line of sight. It is clear that this exposure assessment method is inaccurate because the field strength features large variations even within short distances, in particular, in urban areas due to shadowing effects. For example, a nest on the roof of a building or church is not necessarily in an antenna line of sight. In addition, a directional probe only measures the field contribution coming from the direction where the meter is pointing to. If there are radiations coming from different directions, the exposure is underestimated. In addition, the measurements have been performed with a Nuova Elettronica meter model LX 1435. The instructions how to build this meter were published in a magazine for handyman (Electronique et Loisirs Magazine – April 2000 edition). This meter is not a professional equipment, and its accuracy is inappropriate to measure intensities in the range mentioned by the author (between 0 and 3.5 V/m). It is also well known that the presence of 50 Hz electric and magnetic fields distorts completely the reading. Clearly, results of correlations which are based on the results of measurements made with such a device are highly questionable.

As the field intensity does not only depend on the distance, the fact that 12 nests were found without young at 200 m compared to only one at more than 300 m does not allow to conclude that the radiations are the cause of the findings.

Shortcomings regarding the exposure measurements prevent any scientifically sound evaluation of the impact of mobile phone radiation in abovementioned studies. But other investigations on birds were equally alarming. House sparrows (*Passer domesticus*) are sedentary animals and are for this reason interesting study objects. A first study was conducted in East Flanders (Belgium) where the number of males that were seen or heard at 150 different locations was recorded. The locations were subdivided in six residential areas at a distance of 91–903 m of a mobile phone mast (900 or 1800 MHz frequency band). Most (90%) were within 100–600 m of the mast (average = 352 m). Field measurements were done during 2 min and revealed field intensities of 0.043–0.153 V/m for 925–960 MHz radiation, and 0.017–0.083 V/m at 1805–1880 MHz. As in the above investigation (Balmori, 2005), measurements were obviously not performed where the birds perch (on tree branches, bushes, roof tops, etc.), and it may be assumed that real exposures may be higher than what the measurements reveal.

Spatial variation in the number of house sparrow males was negatively and highly significantly related to the strength of electric fields from both the 900 and 1800 MHz downlink frequency bands and from the sum of these bands. Fewer house sparrow males were seen at locations with relatively high electric field strength values of GSM base stations and therefore support the idea that long-term exposure to higher levels of radiation negatively affects the abundance or behaviour of house sparrows in the wild (Everaert and Bauwens, 2007). A suggested reason is the fact that bird feathers may act as dielectric receptors of high-frequency EMF that may induce piezoelectric effects in the feathers (Bigu-del-Blanco and Romero-Sierra, 1975a, 1975b). Another hypothesis is that radiation from mobile phone base stations may affect the local abundance of insects or other invertebrates and thereby indirectly influence the number of house sparrows. However, this is somewhat in contradiction to observations indicating that RF radiation from radars had no significant effect on the abundance of insects (mentioned in Nicholls and Racey, 2009), but may be in line with other observations in ants (Cammaerts et al., 2012).

As indicated by the authors themselves, this study should be considered as preliminary and non-conclusive for several reasons. First, sampling locations were each visited only once, such that counts of the number of house sparrow males and measurements of electric field strength are subject to some variation and estimation error. Because a highly similar pattern was found in each of the six study areas, they yet believe that this strengthens the possibility that the relationship is not a spurious one. This is indeed possible but a careful analysis of the provided technical data indicates that measurements are most probably incorrect and at the most only slightly informative. The observed correlation with increasing field strength is thus not necessarily correct. Indeed, maximum values (peak hold) of the electric field strengths (in V/m) at each location were measured using a portable calibrated high-frequency spectrum analyser (Aaronia Spectran HF-6080; typ. accuracy ±3 dB) with calibrated EMC directional antenna (HyperLOG 6080; logarithmic-periodic). To measure the maximum radiation values, the EMC antenna was turned around in all directions. However, measuring the electric field strength with a directional antenna, even if it is turned around in all directions, does not provide the correct exposure level. The field strength is at all points the resultant of several contributions due to multipath propagation. There are, in general, one direct path and several reflected paths (on ground, buildings, etc.). A directional antenna (logarithmic-periodic) such as the one used by the authors only measures the field contribution coming from the direction where the antenna is pointing to. In addition, a logarithmic-periodic antenna is only sensitive to one electric field polarisation. Such an antenna underestimates the exposure if the dipole elements are not parallel to the electric field vector. It will even give a null response if the dipole elements and the electric field vector are at right angles to each other. Due to the wave reflection which occurs on various surfaces (ground, walls, etc.) in real environments, the actual field polarisation is rather complex. An underestimation of the exposure level occurs when only one polarisation direction is taken into account. As described in most exposure standards, correct exposure measurement requires vector summation of three orthogonal components of the electric field. The root sum square (RSS) value is defined as the square root of the sum of the squares of three orthogonal components of the electric field. The authors also state that the study areas were exposed to one or more GSM base stations. A (logarithmic-periodic) directive antenna will only give a fraction of one GSM base stations contribution. The only method to measure correctly the exposure in a multipath situation is to use a three-axis isotropic antenna. Such a probe provides the RSS value of the resultant of all the radiations coming from different directions.

If we consider the exposure at a particular point, the method used by the author to measure the exposure is inaccurate due to the fact that the logarithmic-periodic antenna measures only one polarisation orientation of the electric field contribution coming from only one direction. Turning around the antenna in all directions does not allow cumulating the radiations coming from different directions. It does not either provide the RSS value.

The second remark concerns the point where the electric field component was actually measured. Although this aspect is not detailed in the paper, one may assume that the measurements were likely taken at a height of about 1.50 m above the ground (handheld logarithmic-periodic antenna turned around in all directions). It is well known that the EMF intensity increases significantly with the height. A first reason is the antenna directivity which produces a relatively narrow beam. The higher the measurement point, the higher the probability to be closer to the beam axis. Also, and more importantly, radio waves propagation may be blocked near ground level by obstacles such as houses, trees, bushes and hedges (as indicated above, the authors mention that this was the case in the study areas). For example, at 900 MHz, an 80 cm thick hedge produces a 6 dB signal attenuation (i.e. the field strength, in V/m, is divided by 2). If we consider a point located on the top of a two-floor house, let say at about 6 m above ground, the probability for this point to be in the antenna line of sight is much higher than for a point situated at only 1.5 m above ground level. Most of the time, the birds perch on tree branches, bushes, roof tops, etc. Consequently, the EM field intensity as it was measured is likely very different to the value to which the birds are actually exposed most of the time.

The two sources of error described above are very important, especially with respect to the narrow range of the E_{GSM} values. According to the provided data, the E_{GSM} value (in V/m) in the six studied areas ranges from 0.021 to 1.056 V/m. EM-field intensities in this range are typical near ground level around GSM base stations but significantly higher values are generally found at higher places located in the antenna line of sight. For example, the highest measured value (1.056 V/m) is rather low if we take into account the distance from the nearest base station mentioned by the authors (mean = 352 m, range = 91−903 m, about 90% at 100−600 m).

Considering the two above remarks on errors and inaccuracies of the exposure assessment, one may question the validity of the conclusions of the statistical analysis. This is nevertheless an interesting study that should be accompanied by more controlled and accurate measurements.

This holds true for another investigation on house sparrows (Balmori and Hallberg, 2007) where virtually the same comments can be made with regard to the field measurements. These measurements were performed with the same LX 1435 meter which was used in previous work (Balmori, 2005). In this study, significantly low bird densities were also found in areas with high electric field strength as well as a significant decline in mean bird density over time (a 5% annual decrease in the population). According to the authors, the house sparrow may become extinct by 2020 if this trend continues. The authors mentioned also other possible reasons for the decline of the house sparrow (less insects, air pollution, pesticides, competition with other species, transmission of diseases, etc.). They yet consider that these causes do not exclude a major role of RF radiation from base station antennas.

Still another study was conducted on birds. This study was devoted to long-term effects on the breeding biology of tits (*Parus* sp.). Two series of 36 nest boxes located in a radar station aria were considered. Control nests were in the same forest but outside the radar area. Field measurements were done at each nest box separately. For control nest boxes, the exposure was 0.006 W/m^2 on average whereas experimental boxes were exposed to an average of 3.41 W/m^2 (high exposure level) and 1.12 W/m^2 (intermediate exposure level). This study revealed that radar radiation does not result in a decrease of the number of nesting tits but that it may cause shifts in tits species living around the radar station (Rejt et al., 2007).

In conclusion, despite alarming results from many of the investigations and suggestions of, for example, bird feathers acting as dielectric receptors, there often were too many inconsistencies between the results and doubts with regard to the EMF measurements. It should also be noted that some of the reported effects were found at high exposure levels or with frequencies that were not relevant or comparable with radiation from mobile phone base station antennas. Therefore no clear-cut conclusion can be drawn with respect to the effects of, for example, RF radiation from mobile phone masts on birds. Other well designed investigations may be necessary.

F. Amphibia

An experiment was conducted in which eggs and tadpoles of the common frog (*Rana temporaria*) were exposed to radiation from several base station antennas (Balmori, 2010a). Experimental and control groups were kept in tanks with daily renewed food and oxygen on top of a fifth floor terrace at a distance of 140 m from four base stations. The base stations were on the roof of an eight-storey high building. The experiment lasted from the egg phase until an advanced phase of tadpole prior to metamorphosis (2-month period). Controls were placed inside a Faraday cage.

In the exposed group low coordination of movements, asynchronous growth and a high mortality (90%) was observed. Coordination of the controls was normal; the development was synchronous and mortality was low (4.2%).

The author considers that these results indicate that base station antennas may pose an enormous environmental risk, even if other causes were identified to explain amphibian decline (see also Balmori, 2006).

The author states that "measurements of electric field intensity (radiofrequencies and microwaves in V/m) were done in the two tanks containing the tadpoles. They were presumably performed in air outside the tanks but this was not mentioned in the paper. The fields in the water would very likely be much smaller. Measurements were made with the following meters:

- Nuova Elettronica device Model LX 1435 with 10% sensitivity, with unidirectional probe (range: 1 MHz–3 GHz)
- PCE–EM 29 device with an isotropic probe and calibration certificate (range: 50 MHz–3.5 GHz). Resolution: 0.1 mV/m. Absolute error: 71.0 dB.
- Spectrum analyser Advantest R-3272 (range: 9 KHz–26 GHz), probe Rhode & Schwarz HE-200 (Official measurements of the Ministry of Science and Technology from Spain)".

The results of electric field intensity to which the tadpoles were exposed with the different devices were as follows:

- LX 1435: EMF intensity 2.5–3.5 V/m.
- PCE–EM 29: EMF intensity 1,847–2,254 V/m.
- Advantest R-3272: Results in decibels (30 carriers in the FM broadcast radio, television, GSM 900 and DCS 1800 frequency bands with intensity ranging from 37 up to 81).

It is worth noting the large spread between the LX 1435 and PCE–EM 29 results. It confirms the comments made before concerning the inaccuracy of the LX 1435 meter.

The measurements performed with the spectrum analyser do not allow determining the exposure because the units (decibels) used are unclear. It could be dBμV/m, dBm, dBμV, etc. If the unit is dBμV/m (decibel with respect to 1 μV/m), the highest contribution (81 dB for one of the GSM carrier in the 900 MHz frequency band) should correspond to $10^{4.05}$ μV/m = 11,220 μV/m = 0.01122 V/m. Such a value is not consistent with the results provided by the two wideband meters. If the unit is dBm (decibel with respect to 1 mW at the antenna output) or dBμV (decibel with respect to 1 μV at the antenna output), the antenna factor (not given in the paper) is required to compute the field intensity in V/m. As a conclusion, effects may have been found but indications for a causal relationship with electromagnetic fields were not provided.

G. Mammals

1. Cattle

Löscher and Käs (1998) reported about a farmer who observed severe health problems and considerable reduction of milk yield among his livestock. Changes apparently became manifest after the installation of different mobile phone antennas near the farm, in addition to already present antennas for TV and FM broadcasting. Among the health problems, conjunctivitis, irritations and behavioural disturbances were observed. Many of the effects were similar to the effects of chronic stress pressure. Fertility disorders and abortions were also observed. Cows that calved three or four times showed rapid decline ultimately resulting in death.

A cow presenting severe behavioural disturbances was transferred into another herd some 20 km away from the farm. A spectacular recovery was observed after only a few days but symptoms also returned within a few days after the animal's return to the farm. This is why the RF radiation from TV, FM and GSM was suspected to be the cause of the problems although the authors stressed that only a scientifically sound and robust investigation, which was not yet conducted, can provide sufficient proof. As the problems appeared only after the addition of GSM antennas, these were especially blamed. Other antennas that were described as "C-net: 461 MHz; D-net: 935 MHz; Cityruf: 460 MHz and Modacom: 427 MHz" were present before and at that time they did not illicit health problems among the cattle. This is a little bit surprising as FM and TV signals are more penetrating than GSM signals. But they are different yet, and therefore different effects should not immediately be excluded. Also the combination of radiations with overlap of similar frequencies may possibly account for the findings.

Yet, as for most other investigations, this (preliminary) study and testimony is apparently full of shortcomings and provides at the least some highly questionable data. TV frequencies are, for example, between 50 and 840 MHz but measurements were given for TV channels of 2,510 MHz and 3,734 MHz. Results from field measurements were also reported for 512 MHz frequencies but this frequency does not coincide with that of the transmitters on the masts. Yet, fields of 0.0275 V/m were recorded (0.002 mW/m^2 in the stable) up to 0.514 V/m (0.7 W/m^2 in the meadow close to the antennas). No measurements were done in the "control" stable, and the number of cows involved in the study was not reported. It is also clear that conjunctivitis has a multifactorial origin, involving among others, viruses, bacteria and physical agents such as dust and draught.

Improvement of the health status of a cow after delocalisation may be due to so many factors that the presence or absence of RF radiations cannot be seen as the only difference of importance. A difference in feed (different silo), air quality, other treatments etc. can be as important as an explanation for differences in health status. Errors and incoherencies with regard to field measurements indicate that the study was not of a sufficient quality to be persuasive.

In two successive studies, Hässig et al. (2009, 2012) found that the occurrence of nuclear cataract in veal calves was associated with the presence of mobile phone base stations. The first study involved a one-year exposure up to 1 V/m from GSM and UMTS base stations (frequency not specified). Of 253 calves, 32% ($n = 79$) had various degrees of nuclear cataract, but only 3.6% calves ($n = 9$) had severe nuclear cataract. The data showed a relation between the location of the veal calves with nuclear cataracts in the first trimester of gestation and the strength of antennas. There was an association between oxidative stress and the distance to the nearest mobile phone base station. Oxidative stress was increased in eyes with cataract. It has not been shown that the antennas actually affected stress. Prevalence numbers of cataract in veal were however in the same range as those found in an environment where no mobile phone base stations were present (Ashton, 1977). The authors therefore consider that other potential environmental agents cannot be ruled out as being on the origin of cataract (e.g., power lines, highways or industrial plants, ozone concentrations, etc.).

In their second investigation (2012), the authors paid attention to a dairy farm in which a large number of calves were born with nuclear cataracts after a mobile phone base station had been erected in the vicinity of the barn. Calves showed a 3.5 times higher risk for heavy cataract if born there compared to Swiss average. All usual causes, such as infection or poisoning, common in Switzerland, were excluded. Although the authors did find an association with mobile phone radiation, they yet concluded that the real cause of the increased incidence of cataracts remains unknown.

It is well known that RF radiation is cataractogenic due to poor thermoregulation in the eye. Yet, exposure should be high enough to produce heat injury. Although the possibility of a non-thermal factor in cataract formation was considerably debated in the past, it is now assumed that RF-induced cataract is due to thermal injury only. It was, for example, shown that a temperature above 41°C was necessary for production of lens opacities in the rabbit. Radiation-induced temperature elevation appears to be essential for the cataractogenic effect of microwaves (Kramar et al., 1975).

Some investigations in humans have also shown eye injury in occupationally RF-exposed subjects (radar workers, military, radio and TV maintenance workers). However, in all cases, brief, intense exposures (thermal radiation levels) were thought to be quite common. Also, solar radiation exposure, a known risk factor for cataracts, was not considered and could have differed between RF-exposed and unexposed workers (Ahlbom et al., 2004). In a literature review on alleged effects of microwaves on the human eye, Vignal et al. (2009) did not report any significant adverse effect for long-term and low-dose radiation exposures. It is for the above reasons unlikely that the observed cataract in veal calves was due to the radiation from mobile phone masts.

It should be noted yet that an earlier investigation on cows grazing in the vicinity of the Skrunda super-radar station in Latvia reported the presence of a higher frequency of cytogenetic damage in the blood of these animals compared to control animals (Balode, 1996). Here, frequencies of 154 and 162 MHz (different from mobile phone antennas) were involved. According to the authors, the control area was selected based on the similarity to the exposed area, for all factors except electromagnetic radiation. However, it was not possible to find out what this really meant, even after consultation of an earlier paper the authors referred to (Balodis et al., 1993). Other differences between exposed and non-exposed areas (i.e. chemical pollution) may therefore yet exist. There is, for example, a metal smelting industry and an oil refinery in the vicinity of the radio station. Although metal levels (vanadium, Zn) were apparently not more elevated in this area (Balodis et al., 1996), metal contents or other pollutants were not determined in the blood or other tissues of the RF-exposed animals and their controls.

Although not directly comparable because of the involvement of still other frequencies (3–30 MHz, not comparable to those of mobile phone antennas), it also may be worthwhile mentioning another study on cattle (Stärk et al., 1997). This study investigated the influence of short-wave range (3–30 MHz) radio transmitter signals on salivary melatonin concentrations in dairy cattle. No chronic melatonin reduction effect was observed but a small delayed acute effect was suggested. As indicated by the authors, this study was only a preliminary pilot study which included only a few animals. It does not allow any firm conclusion. To our knowledge, no further studies were performed afterwards.

2. Mice

A study was conducted on BalbC mice that were placed at different locations around the antenna park of Thessaloniki where some 100 antennas for commercial TV and FM-radio (transmitting in the VHF and UHF band) were operating (Magras and Xenos, 1997). Power densities varied from 168 nW/cm^2 to 1,053 nW/cm^2. Twelve pairs of mice were divided into two groups and brought to locations with different power densities. RF-exposed mice became sterile after the third (1,053 nW/m^2) or fifth (168 nW/m^2) generation. However, the prenatal development of the young was improved suggesting that the decreased fertility may result in a better access to blood and nutrients for the few remaining foetuses. Thermal effects were also seen as possible reasons for an improved blood flow but this explanation must be rejected because the RF exposure in the described situation is very low (about 1 mW/m^2). As for some studies with *Drosophila*, the authors also envisaged other, i.e. endocrinological causes but these are more likely to be due to other environmental influences as literature data usually do not suggest that RF radiation significantly impairs the endocrine system. Overall it is indeed recognised that developmental and reproductive effects (e.g. increased embryonic and foetal losses, increased incidence of foetal malformations and anomalies, reduced foetal weight at term and impairment of male fertility) may be found after exposure to RF radiation, but only at exposure levels that are sufficiently high to cause significant increase of temperature. There is no consistent evidence of adverse effects at non-thermal exposure levels (cf. Krewski et al., 2007; AFSSET, 2009; Juutilainen et al., 2009; SCENIHR, 2009). Thus, the results of most laboratory investigations on RF-exposed animals are in contradiction with this particular investigation.

A problem with this study is that control animals were not kept in the same (mountainous) environment. This is enough reason for not taking this study into account. Differences in location and possibly stress associated with it may well be the main reason for the observed differences in fertility between control and exposed animals.

3. Bats

Two investigations were devoted to RFs from radar stations and their effect on bats (Nicholls and Racey, 2007, 2009). The purpose of the investigations was not to study possible harmful effects as such but should be seen as an effort to find a way to keep bats away from wind turbines. Large numbers of bats are indeed killed by collisions with wind turbines, and there is at present no accepted method of reducing or preventing this mortality.

Bats were counted at different locations: in close proximity of radar installations (<200 m; >2 V/m), at an intermediate distance (200–400 m; <2 V/m), and at a control site out of sight of the radar (>400 m and a registered field of 0 V/m). Bat activity was significantly reduced in habitats exposed to EMF fields of more than 2 V/m when compared to matched sites registering EMF levels of zero (Nicholls and Racey, 2007). According to the authors, this may be due to thermal effects resulting from a high irradiation surface and high thermal energy already produced by the animals when flying. The authors believe that this may be the reason why bats avoid places where RF radiation is relatively important. This was confirmed in their second investigation (Nicholls and Racey, 2009). The electromagnetic signal from a small portable radar was found suitable as a deterrent to foraging bats. Although bat activity was significantly reduced when the radar was in operation, this reduction was not 100%, and hence not all bats were kept away from the radar. It was also found that the radar had no significant effect on the abundance of insects (which is in contradiction to some claims or hypotheses brought forward by others).

In the second publication (2009), the authors used a small 6 kW peak power X-band radar. Its horizontal and vertical beam widths are, respectively, 1.9° and 22°. With the antenna fixed (i.e. not rotating as when the radar is normally used) and with 0.08 μs pulse length at 2,100 Hz pulse rate (hence a $0.08 \times 10^{-6} \times 2{,}100 = 0.0168\%$ duty cycle), the authors mention "EMF peak hold values" at 10 m, 20 m and 30 m of, respectively, 26.24, 22.99 and 20.25 V/m. The fact that these values nearly do not decrease according to $1/d$ (while they were measured sufficiently far from the source) is questionable. The horizontal and vertical beam widths mentioned above allow estimating the antenna gain to about 32 dB. With a 6 kW peak power and a 0.0168% duty cycle, the classical free-space formula gives an RMS field strength (not the peak value) estimate of 21 V/m at 10 m, 10 V/m at 20 m and 7 V/m at 30 m. These RMS values are in the same order of magnitude than what the authors called "peak hold values". With the 0.0168% duty cycle, the actual peak value is 77 times greater ($1/0.000168^{1/2}$), i.e. about 1,600 V/m at 10 m. Such an exposure is therefore not comparable with that of a mobile phone base station antenna. Although this study may be of importance with regard to its purpose, it is not relevant with respect to the mobile phone debate.

H. Plants

Because of growing concerns about herbicide resistance and chemical residues in the environment, other means to control weed plants are envisaged. These include the application of electrostatic fields, microwaves or electric currents as described by Diprose et al. (1984) and Brodie et al. (2012a, 2012b). The studies showed that microwave energy effectively kills weed plants and their seeds. As the applied fields were high and definitely induced thermal effects, these studies are not relevant for the present review. We therefore will not further consider this kind of investigations.

1. Lichens (Parmelia Tiliacea and Hypogymnia Physodes)

Urech and Herzig (1990) and Urech et al. (1996) found that exposure to 2,450 MHz fields (500 W/m^2) substantially reduced the growth of lichens. However, the exposure level was far exceeding the limit recommendations (10 W/m^2 in Switzerland) and resulted in an important increase in the surface temperature and an accelerated drying process. Such exposure is again not relevant to mobile phone radiation. The exposure of lichens of both species was repeated near a short-wave broadcast transmitter (9.5 MHz, amplitude modulated; maximum field strength 235 V/m, 332 mA/m). Here, no visible effects on the exposed lichens were detected. The experimental results demonstrated that there is a low probability of non-thermal effects.

2. Maize (Zea mays L.)

Seedlings were exposed to 2,450 MHz radiation in a microwave oven. They appeared to be most resistant at sunrise and the least resistant at sundown. Burns along the vascular system and damage to the photosynthetic system were observed. A significant production of carotenes and anthocyanins was also seen at noon. As before, effects could be ascribed to a thermal insult only (Jonas, 1983).

The effects of microwave irradiation on growth, germination and absorbance efficiency of photosynthetic pigments of maize grains were investigated by exposing maize plants to continuous microwaves (935.2–960.2 MHz with intensities 0.07–0.15 mW/cm^2) produced by a base station antenna installed on a tower at 8 m above ground level. Test plants were placed on the ground at 3 m, 6 m, 9 m, and 12 m from the base of the tower. Control plants were placed away from the antenna. Test- and control plants were subjected to the same environment during four weeks. The present experiment showed that germinating grains, growth rate of exposed maize seedling and absorbance efficiency significantly increased compared to the control. Photosynthetic pigments, total soluble sugar and total carbohydrates were positively affected by the microwave exposure. Microwaves also altered the anatomical features of maize leaves. In all measured variables, differences between the control and the microwave exposed plants occurred (Khalafallah and Sallam, 2009). However, the microwave power densities given by the authors (0.07–0.15 mW/cm^2, which corresponds to an electric field between 16.2 and 23.8 V/m) are not consistent with the exposure conditions although the antenna input power is not known. Indeed, usually, a base station antenna installed as described in the paper (8 m above ground) produces, in the vicinity of the tower base, an electric field which rarely exceeds 1 or 2 V/m.

3. Cress (Lepidium Sativum L.)

Low-intensity millimetre waves inhibit the growth of cress roots (Kremer et al., 1985). The effect is reversible but starts immediately after the onset of irradiation. Power densities of 6 mW/cm^2 completely halted the root growth. The effect did not appear to be frequency dependent but to depend strongly on the polarisation of the microwaves with respect to the root orientation. Despite a moderate temperature increase (0.3°C), it was assumed that the observed effects are primarily caused by induced thermal gradients across the surface of the root tip.

4. Trees (Beech, Pines and Conifers)

It was shown that pollen germination of Norway spruce and Scots pine can be stimulated by low doses of X-rays and radar waves (1-min exposure to 2.7–6 mW/m^2 power densities). Longer exposures inhibited germination. Radio waves with a wavelength of more than 3 m and electrostatic fields were not effective (Krug, 1990).

A previous study on the impact of the Skrunda radar station in Latvia (frequency range 154–162 MHz—radiated power: 1.3 MW) already suggested effects on the growth and the development of pine trees (Balodis et al., 1993, 1996). There was a correlation between the relative additional increment in tree growth and the distance from the radar. The authors did not report effects of many other environmental and anthropogenic factors, hence suggesting that the EMFs are indeed responsible for the findings. There was, for example, no relation to chemical pollutants whereas the loss in additive growth increment in the radiated zone began with the radar installation in the early 1970s.

It is important to point out that the conclusions are based on a correlation between tree growth and distance from the radar. If the landscape is not flat or if some trees are in line of sight of the radar and others are not (the paper does not give any information on this), the distance from the radar cannot replace the EMF intensity measurements to be used in the correlation analysis. It is therefore regrettable that the correlation has not been based on results from actual exposure measurements.

A similar study on three locations close to the Skrunda radar station with high (250 and 79.4 mV/m), intermediate (9.5 mV/m) and low (0.04 mV/m) EM field exposure suggested the induction of cytological changes in the pine needles, especially an unspecific response resulting in accelerated resin production and promoted senescence of pine trees (T. Selga and M. Selga, 1996). Actual exposure measurements were carried out in this study but the result (maximum of 250 mV/m) seems very low with respect to the high power of the radar. Unfortunately, the paper does not provide enough details about radar height, pulse duration, terrain profile, distances, etc. to check the given figures.

Another investigation was performed in the forest area south of the St. Christchona transmitter and north of TV and ultra short-wave transmitters of Bantiger close to Basel (Switzerland). The investigation was devoted to conifers, pine and beech trees. Analyses of the density of the foliage or needles of 800 trees were carried out as well as of their growth (Joos et al., 1988). No effects were seen. Trees close to an electromagnetic source (power density around 3×10^{-2} mW/m^2) were not different from trees in a "non-exposed" area (power densities 100–1,000 times lower than in the exposed area). Also, no decreased growth was seen after 1981 indicating that RF radiation did not impair their health. This study is therefore not in accordance with several others. Although the quality of this study seems excellent, the very low exposure in the exposed area (about 0.1 V/m) tempers the relevance of the results. The same holds true for another Swiss study where the health condition of trees in the Swiss forest around Mt. Gibloux has been assessed with the Sanasilva crown photos (infrared red aerial views). This area was irradiated by TV and ultra short-wave transmitters at a rather low exposure level (about 0.1 mW/m^2). Due to the high number of trees that were involved in the study (approximately 60,000), the statistical power of the study was high. No damage was seen to the exposed trees compared to those from non-exposed areas (Stäger, 1989).

Schmutz et al. (1996) investigated the long-term (>3.5 years) effects of 2,450 MHz microwave exposure on young spruce and beech trees.

TABLE 3. Summary of responses (accumulation of stress-related transcripts) following a 900 MHz electromagnetic stimulation of different amplitudes and exposure times

Duration (min)	Amplitude (V/m)	Transcript	Response	References
1	5	bZIP	NO	Unpublished
2	5	CaM, CMBP, PIN2	NO	Beaubois et al. (2007), Roux et al. (2006) and Vian et al. (2006)
10	0.5	bZIP	NO	Beaubois et al. (2007) and Vian et al. (2006)
10	5	bZIP, CaM, CMBP, PIN2	YES	Beaubois et al. (2007) Roux et al. (2006) and Vian et al. (2006)
10	40	CaM, CMBP, PIN2	YES	Id.

Therefore, they used a 600 W microwave generator which was responsible for a temperature increase of 4°C. Despite high intensities above the Swiss exposure limit of 10 W/m^2, no visible effects were observed (e.g. crown transparency). Growth and photosynthesis in beech leaves were unaltered but there was a negative relationship between foliar concentrations of calcium and sulphur in beech and the power flux density during the first two years of exposure. However, the concentrations of both nutrients remained within the sufficiency range. In the third year of exposure, the effect was absent.

Above investigations probably need to be confirmed by others, but in the meantime it is clear that they do not support the hypothesis that RF radiations from transmitters harm trees and forests.

5. Tomatoes (Lycopersicon Esculentum)

A research group at Blaise Pascal University (France) investigated RF effects on tomato plants (*Lycopersicon esculentum*). According to them, these plants are ideal model systems to investigate environmental stress responses, and shortcomings of studies on many other organisms can be avoided. Variables as, for example, light, temperature, nutrients, etc. can be easily controlled. As animals develop more in *volume* compared to plants which develop more in *surface*, plants will comparably be more exposed to, for example, RF radiation. This was also seen as an important asset. The authors used a specially designed facility (the mode-stirred reverberation chamber) to expose tomato plants to low level (900 MHz, 5 V/m) EMF "comparable to those that may occur in the environment but without the unwanted external electromagnetic fields" (Roux et al., 2008a, 2008b). They investigated molecular changes, for example, changes in abundance of specific mRNA's soon after exposure. A summary of the results is given in Table 3 (Vian et al., 2007).

Plants are very sensitive to environmental signals. The results apparently show that measurable molecular changes occur shortly after EMF stimulation. However, up to now, the significance of these findings is not clear. As for many other investigations, the significance was furthermore sometimes minimised due to methodological shortcomings, as for example, the absence of any SAR evaluation. For this reason the results may not be overestimated, but they may also not be disregarded.

6. Other Plants

Exposing seedlings of the flax, *Linum usitatissimum* L., to a variety of weak environmental stresses plus a 2-day calcium deprivation triggers the common response of production of epidermal meristems in the hypocotyl. The same response was induced by a 1-min cold shock. Epidermal meristem production was also induced by a single 2 hr exposure to radiation emitted at 0.9 GHz at non-thermal levels by a GSM telephone (Tafforeau et al., 2002), whereas a single 2 hr exposure to radiation emitted at 105 GHz at non-thermal levels also induces meristem production with kinetics similar to that induced by weak environmental stimuli (Tafforeau et al., 2004). In these experiments, the seedlings were exposed at a mean power density (estimated by the authors) of the order of 10 W/m^2 (non-thermal levels) under continuous artificial light (6.4 W/m^2 irradiance). The same effects are thus produced by different environmental signals. According to the authors, it cannot be excluded that different, specific, biological processes are perturbed separately and that these perturbations generate a common stress response. They also stress that the effects do not necessarily have an adverse consequence as other abiotic treatments such as simply touching also lead to flax seedlings producing meristems after calcium deprivation. The seedlings show no evidence of damage, and their growth rate, buds and shoots are all normal (Tafforeau et al., 2004). This indicates that, as for the experiments on tomato plants, results from this kind of investigations should not be taken as proof of adversity from mobile phone radiation.

Similar experiments were also conducted with Bidens (Asteracea) and Arabidopsis (Brassicaceae). It was obvious from these (and the previous studies) that plants are very sensitive to stimuli from the environment (e.g. wind, cold shock, rain, contact, pricking, wounding). The information received by the seedlings following a stimulus may furthermore be stored within the seedlings and be later on recalled by subjecting the seedlings to a second, appropriate treatment (Tafforeau et al., 2006).

These experiments indicate that effects may be observed after GSM mobile telephone radiation but that these are not particularly alarming as they are of the same nature as other weak (and normal) stimuli.

IV. COMMENTS

An overview of the investigations is given in Table 4, which gives an indication of the exposure levels (as reported by the authors), the study design,

TABLE 4. Review of the reported studies (dosimetry according to the authors)

Organism	Exposure	Conversion into V/m and SAR (approximation)	Study	Effect/comments	References
Insects *Bees*	2,450 MHz, CW, 30 min exposure. 3–500 W/m^2	33.63–434.17 V/m 0.024–3.96 W/kg	Orientation, behaviour, memory	No	Gary and Westerdahl (1981)
Insects *Bees*	1,900 MHz with 100 Hz modulation, DECT, average transmission power 2.5 mW. Placed permanently in standby mode under the honeycombs	?	Weight of frames of honey combs and foraging flight behaviour (returning behaviour, quantity of returning bees as well as returning time)	Yes No exposure assessment done	Harst et al. (2006) Kimmel et al. (2007) (*same lab as above*)
Insects *Bees*	1,900 MHz GSM Motorola SLVRL7—SAR = 1.34 W/kg; 1.41 ± 0.483 μW/cm^2.	72.9 V/m 1.34 W/kg	Proboscis extension and feeding Return to target aggression	No No exposure assessment details given	Mixson et al. (2009)
Insects *Bees*	GSM 900 MHz; exposure continuous for 15 min twice per day and twice per week. Electric field strength 56.8 V/m; power flux density 8.549 μW/cm^2 (incorrect in text!)	Probably 179 V/m 1.51 W/kg	Honeybee behaviour; flight/returning activity, pollen-foraging efficiency, queen prolificacy, etc.	Yes Study was highly criticised for several reasons (small number of hives, insufficient controls and field measurements, etc.)	Sharma and Kumar (2010)

(Continued on next page)

TABLE 4. Review of the reported studies (dosimetry according to the authors) *(Continued)*

Organism	Exposure	Conversion into V/m and SAR (approximation)	Study	Effect/comments	References
Insects *Drosophila*	GSM 900 MHz and 1800 MHz; PW at different electric field strengths.		Fertility, reproductive ability, ovarian cell death	Yes Effects are apparently more important at 900 MHz than at 1800 MHz and seem to be dependent on the field intensity and less on the carrier frequency. Measurements appeared to be not adequate, and data are therefore questionable. Effect may be thermal contrary to the author's conviction.	Panagopoulos et al. (2004) Panagopoulos et al. (2007) Panagopoulos et al. (2010)
Insects *Drosophila*	1900 MHz, SAR = 1.4 W/kg; 10 days exposure	1.4 W/kg	Effects on developmental period, from egg laying to pupation	Elevated numbers of offspring and effects on cellular functions (increased levels of *hsp*70, etc.)	Weisbrot et al. (2003)
Ant	900 MHz, GSMK modulated; 10 dBm	0.77 V/m = 7.95×10^{-5} mW/cm^2 = 0.01 mW/kg	Scoring olfactory and visual memory	Yes Loss of acquired visual but also olfactory memory	Cammaerts et al. (2012)

Spider	9.6 GHz, PW, 16 hr continuous exposure; power flux density 10, 1, 0.1 mW/cm^2 (estimated SAR = 40, 4, 0.4 mW/kg)	19.42; 6.14 and 1.94 V/m 7.92; 0.79 and 0.079 mW/kg	Web-spinning ability	No Exposure not further characterised	Liddle et al. (1986)
Snail	1900 MHz, 48 mW/kg, 1 hr	48 mW/kg	Reaction time to thermal pain	Yes GSM-exposed snails were less sensitive to thermal pain as compared to sham controls	Nittby et al. (2012)
Birds *Homing pigeons*	150 KW radio transmitter, 7.5–21.8 MHz	?	Orientation/homing success	No No influence on homing success and vanishing time. No disruption of the orientation system.	Bruderer and Boldt (1994)
Birds *White-throated sparrow and dark-eyed junco*	Acute exposures to 2.45 GHz, power flux densities of 25 mW/cm^2 (20 and 200 min exposure), 100 mW/cm^2 (20 min), 155 mW/cm^2 (7 and 10 min).	30.7; 61.4 and 76.44 V/m 19.79; 79.18 and 122.73 mW/kg	Cognitive/behavioural endpoints: dominance behaviour/hierarchy —aggression—avoidance	Yes (aggression) Experiments were done in captivity.	Wasserman et al. (1984b)

(Continued on next page)

TABLE 4. Review of the reported studies (dosimetry according to the authors) *(Continued)*

Organism	Exposure	Conversion into V/m and SAR (approximation)	Study	Effect/comments	References
Birds *White stork*	900–1800 MHz fields from mobile phone antennas, PW, continuous exposure. Electric field strength 2.36 V/m (nest within 200 m) and 0.53 V/m (nest farther than 300 m)	2.36 and 0.53 V/m 0.26 and 0.013 W/kg (at 900 MHz); and 0.13 and 0.0067 W/kg (at 1800 MHz)	Effect on reproductive ability, breeding success	Yes No attempt to investigate other possible (confounding) factors. Field measurements with 1MHz-3GHz probe (includes other than mobile phone frequencies)	Balmori (2005)
Birds *House sparrow*	Birds in the vicinity of radiating towers; Measurement with 1 MHz–3 GHz probes show an average electric field strength = 3.5 V/m	3.5 V/m	Number of house sparrows	Yes Significant low bird densities in areas with high electric field strengths. According to authors, sparrows are completely absent in areas with >4 V/m electric fields. Field measurements with 1 MHz–3 GHz probe (includes other than mobile phone frequencies)	Balmori and Hallberg (2007)

Birds *House sparrow*	Birds in the vicinity of radiating towers. Mobile phone base stations, 925–960 MHz (0.043–0.153 V/m) and 1,805–1,880 MHz. (0.083–0.17 V/m)	0.043–0.153 V/m = 0.00009–0.0011 mW/kg (at 925 MHz) and 0.083–0.17 V/m = 0.00016–0.00069 mW/kg (at 1,805 MHz)	Number of male house sparrows at different locations	Yes Spatial variation among sampling locations in the number of house sparrow males was negatively related to the electric field strength.	Everaert and Bauwens (2007)
Birds *Tits*	1,200–3,000 MHz pulsed radiation from radar stations. Radiation exposure on average 3.41 ± 1.38 W/m^2 or 1.12 ± 0.84 W/m^2. Controls were at 0.0062 ± 0.0007 W/m^2 on average.	35.85 V/m = 45.7 mW/kg (at 1200 MHz) and 27 mW/kg (at 3,000 MHz); or 20.55 V/m = 15 mW/kg (at 1,200 MHz) and 8.87 mW/kg (at 3,000 MHz) 1.53 V/m (controls)	Effects on breeding biology of tits living and building nests around the radar stations: number of inhabited nest boxes, number of eggs.	Yes Radar radiation generally does not lead to decreased numbers of nesting tits, but may cause a shift in tits species living around the radar station.	Rejt et al. (2007)

(Continued on next page)

TABLE 4. Review of the reported studies (dosimetry according to the authors) *(Continued)*

Organism	Exposure	Conversion into V/m and SAR (approximation)	Study	Effect/comments	References
Amphibia *Common frog*	Tadpoles placed in tanks on the fifth floor terrace at a distance of 140 m from several base stations: 648–2,155 MHz, continuous exposure from egg up to metamorphosis. Electric field strength = 1.8–3.5 V/m	1.8–3.5 V/m = 0.2–0.81 mW/kg (at 648 MHz) and 0.068–0.26 mW/kg (at 2,155 MHz)	Effects on growth, teratogenic effects, coordination of movement and mortality	Yes Exposed groups show low coordination of movement, asynchronous growth and high mortality. Lack of sufficient and correct dosimetry, no attention to other potential influences (confounders)	Balmori (2010a)
Mice *Balb C laboratory mice*	Mice were caged at different locations at the Thessaloniki antenna park radiating at 88.5–950 MHz. Altitude 570–730 m. At these locations, RF power densities between 168 nW/cm^2 and 1,053 nW/cm^2 were measured.	0.08 V/m = 0.00029 mW/kg (at 950 MHz), and 0.2 V/m = 0.0018 mW/kg (at 950 MHz)	Prenatal development, fertility	Yes A progressive decrease in the number of newborns was found which ended in irreversible infertility. On the other hand, prenatal development was improved. It was not possible to use RF-free controls at the mountain sites. So, control animals were not kept in the same environment.	Magras and Xenos (1997)

Bats	Radar installation, operating frequency:1–4 GHz; E > 2 V/m near source in a distance <200 m and E < 2 V/m between 200 and 400 m distance from the source Portable radar, frequency not specified, PW. Exposure duration of 20 hr (bat activity) and 16 hr (insect count) Electric fields strengths between 3.79–5.58 V/m peak value (at a distance of 10–30 m, field 1), 20.25–26.24 V/m peak value (10–30 m, field 2) and 17.67–25.52 V/m peak value (10–30 m, field 3)	>2 3.79–5.58 V/m 20.25–26.24 V/m 17.67–25.52 V/m	Testing aversive response in foraging bats Testing aversive response in foraging bats and aerial insects	Yes The study was designed to test whether RF fields could be used as a method of preventing bats from death caused by collisions with wind turbines. Bat activity was significantly reduced in habitats exposed to EM field strengths of greater than 2 V/m. This was explained as the result of thermal induction (hyperthermia). Reduced bat activity and foraging effort in radar beam. But substantial numbers of bats continued to forage within the radar beam. The radar had no significant effect on the abundance of insects captured by traps.	Nicholls and Racey (2007) Nicholls and Racey (2009)
Cattle *Cow*	Dairy cows maintained in close proximity to a TV- and radio-transmitting antenna (2.2–18.7 GHz, mean performance = 124 W; 461 MHz, 34 W; 935 MHz, 25 W; 60 MHz, 20 W; 460 MHz, 50 W; 87,361 MHz, 2 W; 2,510 MHz,20 kW; 3,734 MHz, 20 kW; 427 MHz, 15 kW)	?	Behaviour, milk yield	Yes Behavioural abnormalities of some cows (not all) including lowered milk production, irritations, conjunctivitis, vertigo and general declined health status, up to mortality in some cases. A cow with abnormal behaviour recovered when brought into another area but symptoms returned once back in the original stable. Problems came only after the installation of mobile phone antennas. Study was criticised for several methodological errors and apparent errors in field measurements.	Löscher and Kas (1998)

(Continued on next page)

TABLE 4. Review of the reported studies (dosimetry according to the authors) *(Continued)*

Organism	Exposure	Conversion into V/m and SAR (approximation)	Study	Effect/comments	References
Cattle *Latvian brown cow*	Cows exposed to radiation of 154–162 MHz frequency from the Skrunda Radio Location Station	?	Cytogenetic analysis (micronuclei) in erythrocytes	Yes Statistically significant differences were found in the frequency distribution of micronucleated erythrocytes between the control and exposed groups. No field measurements were performed. No confounding factors analysed or evaluated but controls were said to be "matched" (except for the RF exposure)	Balode (1996)
Cattle (veal calves)	Frequencies not specified. 0.17–0.5 V/m	?	Cataract formation and oxidative stress.	Yes Oxidative stress was increased in eyes with cataract. Calves showed a 3.5 times higher risk for heavy cataract if born near a mobile phone base station compared to Swiss average.	Hässig et al. (2009) Hässig et al. (2012)
Cattle	Max. 3 × 150 kW transmitter; 3–30 MHz; cattle at 500 m (= exposed; 1.59 mA/m) and 4,000 m (= controls; 0.076 mA/m) from the transmitters	0.59 V/m = 0.036 mW/kg at 30 MHz	Salivary melatonin concentration measured over a period of 10 consecutive days.	Possible No chronic melatonin reduction but possible acute-delayed effect.	Stärk et al. (1997)
Plants *Lichen*	Field 1: 2.45 GHz, CW, 24 hr/day up to 800 days. 0.2 mW/cm^2–50 mW/cm^2 Field 2: 2.45 GHz, CW, 14 hr, 50 mW/cm^2 Field 3: 9.5 MHz, CW, 15 hr/day up to 300 days, electric field strength 235 V/m max. value, power 250 kW.	2.7–43.42 V/m = 0.15–39.6 mW/kg 43.42 V/m = 39.6 mW/kg	Effect of EMFs on the growth rates of two different species of lichens.	Yes 2.45 GHz: Significant reduced growth rate when exposed with a power density of 50mW/cm^2. No effect at <5 mW/cm^2. A thermal mechanism is suspected. No effects at 9.5 MHz.	Urech et al. (1996)

Plants *Maize*	Maize seedlings irradiated in a microwave oven set at "pre-heat" (= 72.34 $W/cm^2/s$)	5222 V/m/s	Effect on biomass, photosynthesis/pigment production.	Yes Burns along the vascular system and damage to the photosynthetic system were observed. The production of carotenes and anthocyanins was significant in plants irradiated at noon. Effects seem to be due to a thermal insult.	Jonas (1983)
Plants *Maize*	Tem cell, 418 MHz, CW, power density = 0.6 mW/cm^2. Exposure time 1, 2, 4 and 12 hr. "Or" 1 mW/cm^2 at 10.75 GHz	4.7 V/m = 2.25 mW/kg (at 418 MHz) 6.1 V/m = 1.77 mW/kg (at 10 GHz)	Effect on plant growth, photosynthesis	Yes Increase in photosynthetic pigment levels after short exposure periods (1–4 hr) but pigment content diminution at longer (12 hr) exposure period. The authors assume that exposure was non-thermal.	Ursache et al. (2009)
Plants *Cress*	Millimetre wave irradiation, 42–58 GHz ± 25 MHz; power density of 0.2–6 mW/cm^2	2.75–15.04 V/m	Effect on growth	Yes Reversible inhibition of growth. The 6 mW/cm^2 results in a complete halting of the root growth. The microwave-induced temperature increase at the surface of the root tip was found to be less than 0.3°C, but it was yet concluded that the effects were caused by small local irradiation-induced thermal gradients across the surface of the root tip. Similar temperature increases by infrared light had the same effects.	Kremer et al. (1985)

(Continued on next page)

TABLE 4. Review of the reported studies (dosimetry according to the authors) *(Continued)*

Organism	Exposure	Conversion into V/m and SAR (approximation)	Study	Effect/comments	References
Plant Norway spruce and Scots pine	Dipole antenna (ultra shortwaves), 98.5 MHz, λ = 3 m, 0.2 –0.6 V/m, 48 hr exposure. Radar (8–9 GHz) with 1,280 Hz pulses (2.7, 6, 9 and 12 mW/cm^2.	0.2–0.6 V/m = 0.0042–0.037 mW/kg 10.1, 15.04, 18.42, 21.27 V/m = 2.14 up to 9.5 mW/kg	Effect on pollen germination	Yes (radar) X-rays, radar and electrostatic fields do influence the germination. No effect seen with ultra short waves.	Krug (1990)
Plant *Pine*	Four sampling plots near the Skrunda Radio Location Station in Latvia. Frequencies of radiation ranged from 154 to 162 MHz with pulses of 375 $\mu W/cm^2$. Field intensities were 0.04 mV/m (control), 9.5 mV/m (low-level exposure), 79.4 and 250 mV/m (high-level exposure).	9.5, 79.45 and 250 mV/m = 0.00001 up to 0.0065 V/m	Cytological changes in seeds germinated from pine needles and cones found in the sample areas.	Yes Germination increased following low-level exposure but decreased at high exposures. Cytological changes found in seeds from moderate- and high-level exposures (e.g. Golgi apparatus). Accelerated resin production.	T. Selga and M. Selga (1996)
Plant *Different trees (pine forest, beech trees)*	Forests near St. Christchona station and North-East from the ultra short-wave and TV station from Bantiger (Basel). Different frequencies (50–800 MHz). Exposures were dependent according to location (1–10 km from the station): $\sim 3 \times 10^{-6}$ mW/cm^2–10^{-8} mW/cm^2	0.03 and 0.0019 V/m = <0.0001 mW/kg (at 50 MHz) and <0.00005 mW/kg (at 800 MHz)	Effect on density of leaves and growth	No No effect found in relation with exposure level. Even highly exposed trees did not differ from "normal".	Joos et al. (1988)

Plant *Different trees (pine forest, beech trees)*	Forests near Mount Gibloux and Riaz (control site) near Fribourg. Different frequencies and power densities.		Analyses of forest trees based on aerial infrared-red photographs at different locations (Sana-Silva maps).	No No difference between control and exposed areas.	Stäger (1989)
Plant *Beech trees*	Permanent exposure of young plants with 2,450 MHz, 3.5 years. A 600 W microwave generator was used resulting in power flux densities of 0.007–300 W/m^2. Temperature increase of 4 °C at the highest power flux densities (>10 W/cm^2)	1.62–336.3 V/m = 0.055–2376 mW/kg > 61.4 V/m = > 79.1 mW/kg	Visual symptoms of damage	No visual symptoms of damage. No effect on crow transparency, height growth and photosynthesis. Calcium and sulphur concentrations decreased at the highest flux densities but went never outside the sufficiency range.	Schmutz et al. (1996)
Plant *Tomato*	Several studies in which tomato plants were exposed in a specially constructed exposure chamber (900 MHz fields). According to the authors, exposures were at 0.5 V/m, 5 V/m and 40 V/m. Exposures were for 1, 2 and 10 min.	0.5, 5 and 40 V/m = 0.01, 1.18 and 75.6 mW/kg	Stress-related responses	Yes A 10 min exposure at 5 and 40 V/m resulted in accumulation of a number of stress-related transcripts. This study was criticised. It was assumed that the particular exposure situation was responsible for the effects (e.g. stems acting as antennas). No SAR estimation, etc.	Roux et al. (2006) Vian et al. (2006) Beaubois et al. (2007)

(Continued on next page)

TABLE 4. Review of the reported studies (dosimetry according to the authors) *(Continued)*

Organism	Exposure	Conversion into V/m and SAR (approximation)	Study	Effect/comments	References
Plant Flax	Single 2-h exposure of seedlings to radiation emitted at 0.9 GHz at non-thermal levels by a GSM telephone at non thermal levels. Exposure was accompanied by a 2-day calcium deprivation		Response of production of epidermal meristems in the hypocotyl	Yes Decreases in calcium, sodium and potassium and an increase in magnesium that did not alter substantially the overall ratio of divalent to monovalent cations.	Tafforeau et al. (2002)
Plant Flax	Seeds were cultivated in a culture room and exposed to 105 GHz for 2 h using a 50 mW Gunn oscillator mounted above them. Estimated mean power density = 10 W/m^2 at the base of the hypocotyls. The seedlings were exposed to a continuous artificial light (6.4 W/m^2 irradiance). Exposure was accompanied by a 2-day calcium deprivation	61.4 V/m 49.12 V/m	idem	A single 2 h exposure to the radiation at non-thermal levels induces meristem production with kinetics similar to that induced by weak environmental stimuli	Tafforeau et al. (2004)
Plant Bidens and Arabidopsis seedlings	idem		idem	**Changed protein spots **All investigations of this research group showed the vulnerability of the plants to environmental stimuli (wind, rain, contact, pricking, wounding, etc) and the presence of mechanisms of memory processing in the plants.	Tafforeau et al. (2006)

MHz, GHz: megahertz or gigahertz with Hertz (Hz) = frequency (per second); DECT = digital-enhanced cordless telephone; W = Watt; W/m^2 = watt per m^2; nW, μW, mW = nano-, micro-, milliwatt with nano = 10^{-9}, micro = 10^{-6}, milli = 10^{-3}; V = Volt; V/m = volt per metre; PW = pulsed wave, CW = continuous; E = electric fields (in V/m); SAR = specific absorption rate.

results and comments. Besides the above-mentioned investigation, some other papers were devoted to the effects of RF radiation on fauna and flora in the environment. These papers were review papers that should be seen more as position papers than that they add much more to the discussion (Balmori, 2006, 2009, 2010b; Panagopoulos and Margaritis, 2008). Therefore we will not review them here although the interested reader may like to refer them. We consider them "position papers" because they are often selective and only mention investigations that show adverse effects, ignoring those studies that do not. The authors did not provide a rationale for this selection. This is not surprising as they were also authors of many of the investigations that we reviewed in the present paper and that were all "positive". They of course did not criticise their own studies the way we did.

Overall, we learned from the above review that:

- Many of the papers do have shortcomings that may in some cases be very important, therefore minimising the significance of the findings;
- Especially shortcomings in the technical aspects (dosimetry) were obvious. For this reason, correlations between exposure and effect are often of no or reduced significance;
- Alarming results were often ascribed to thermal effects, and in many cases where non-thermal effects were assumed critical evaluations do show that this is probably not the case;
- Confounders and biases may often also weaken the importance of the findings. Often such confounders and biases could not be avoided;
- Many investigations yielded results that were insufficiently robust from a statistical point of view;
- In many studies, ELF and RF-EMF were mixed and confounded;
- Many alarming studies were published in scientific journals which lack any or a serious peer review process;
- Some of the most convincing negative studies had authors who were linked to the involved industry or were published in journals from the sector (Joos et al., 1988; Stäger, 1989; Schmutz et al., 1996; Urech et al., 1996);
- We particularly criticised a number of alarming investigations because they are the most important when one wants to see if effects from RF radiation from mobile phone masts indeed occur. This does not mean that all "negative" studies are free of shortcomings. We nevertheless could not find shortcomings in many of the negative studies that we critically approached. Some of the negative studies however concerned very weak RF exposures;

- Most studies reported experiments involving short term exposures. Data on long term exposures (in terms of decades) are totally missing;
- Effects on fertility are puzzling in this sense that also environmental RF exposures seem to be effective in altering normal reproduction. But these studies are in contradiction with most data from laboratory investigations that convincingly show that such effects can only occur following a thermal insult (e.g. NRPB, 2004; Juutilainen et al., 2009). Endocrine disruptors may also impair reproduction and development but there are no indications that may justify the classification of RF radiation among the endocrine disrupting agents;
- When we assume that field measurements were correct, no dose-effect relationship was found when all investigations were considered. Effects (or absence of effects) were found for as well high as low exposure levels. The size of the effects also varied greatly;
- Although environmental electromagnetic fields were in individual studies very often associated with biological effects from mobile phone masts it should be realized that effects might be caused by the simultaneous exposure to multiple fields strengths and frequencies and by other environmental confounding variables;
- Not all observed effects are harmful. They can often be seen as a normal biological process without any consequence;
- It should be realized that RF-bioeffect studies should be multidisciplinary, and hence need to be conducted by RF-radiation experts (engineers) and biological or medical researchers. This was clearly not always the case. Ideally, the peer review process should also be conducted by experts who cover all important aspects of the science. However, this was not always the case either. Not all peer reviewed papers are of a high quality.

We have seen that a lot of studies did show biological and often adverse effects on animals and plants. The many critics formulated above should be seen as a warning against too hasty conclusions. Yet, it should also be said that we cannot prove or even provide solid arguments that many of the conclusions that were reached by the authors are wrong, even if parts of their study (e.g. dosimetry) did show evident errors and did induce severe doubts rather than that they provided arguments supporting their conclusions.

V. CONCLUSION

With above considerations in mind, we should conclude that overall, many alarming investigations exist but that their interpretation is very difficult. To start with, it should be noted that "a long list of reports of positive results yielded by inadequate experiments may appear impressive and yet mean little" (Beers, 1989). Many of the experiments are inadequate, especially with regard to the field measurements. The present investigations therefore prevent any reliable assessment of the relationship between exposure levels and a biological effect. Biological observations are often 'what they are' but the experiments were in many cases also deficient for a number of reasons (e.g., too small sample size, inadequate controls, over-interpretation of the results, etc.). Furthermore, one should also be aware of possible shortcomings that can only be detected by the people actually present during the experiment.

Therefore, the studies so far do not prove or even do not strongly suggest that environmental exposures to mobile phone base station radiation (and other environmental RF-exposures) are harmful to wildlife. The many positive studies only indicate that additional investigations need to be undertaken. However, to be valuable, such studies should be as rigorous as possible and comprise a complete description of correct experimental conditions and dosimetry.

ACKNOWLEDGMENTS

The author would like to sincerely thank Ir. Willy Pirard (ISSeP, Liège) for his numerous and valuable comments with respect to the technical aspects and critics formulated on many of the published works. The present review was only possible with his invaluable help.

REFERENCES

AFSSET. (2009). *Mise à jour de l'expertise relative aux radiofréquences*. Rapport d'expertise collective. Saisine n°2007/007. http://www.afsset.fr/upload/bibliotheque/964737982279214719846901993881/Rapport_RF_20_151009_l.pdf. Accessed 13/07/2012.

Ahlbom, A., Green, A., Kheifets, L., Savitz, D., and Swerdlow, A.; ICNIRP (International Commission for Non-Ionizing Radiation Protection) Standing Committee on Epidemiology. (2004). *Environmental Health Perspectives* 112, 1741–1754.

Alaux, C., Ducloz, F., Crauser, D., and Le Conte, Y. (2010). Diet effects on honeybee immunocompetence. *Biology Letters* 6, 562–565.

Anonymous. (2009). Microbiology: Colony collapse cured? *Nature* 458, 949.

Atli, E., and Unlü, H. (2006). The effects of microwave frequency electromagnetic fields on the development of *Drosophila melanogaster*. *International Journal of Radiation Biology* 82, 435–441.

Balmori, A. (2005). Possible effects of electromagnetic fields from phone masts on a population of white stork (*Ciconia ciconia*). *Electromagnetic Biology and Medicine* 24, 109–119.

Balmori, A. (2006). The incidence of electromagnetic pollution on the amphibian decline: Is this an important piece of the puzzle? *Toxicological and Environmental Chemistry* 88, 287–299.

Balmori, A. (2009). Electromagnetic pollution from phone masts. Effects on wildlife. *Pathophysiology* 16, 191–199.

Balmori, A. (2010a). Mobile phone mast effects on common frog (Rana temporaria) tadpoles: The city turned into a laboratory. *Electromagnetic Biology and Medicine* 29, 31–35.

Balmori, A. (2010b). The incidence of electromagnetic pollution on wild animals: A new "poison" with slow effect on nature? *Environmentalist* 30, 90–97.

Balmori, A., and Hallberg, O. (2007). The urban decline of the house sparrow (*Passer domesticus*): A possible link with electromagnetic radiation. *Electromagnetic Biology and Medicine* 26, 141–151.

Balode, Z. (1996). Assessment of radio-frequency electromagnetic radiation by the micronucleus test in bovine peripheral erythrocytes. *The Science of the Total Environment* 180, 81–85.

Balodis, V., Kalviskis, K., Ramans, K., Liepa, I., Brumelis, G., Magone, I., and Nikodemus, O. (1993). Environmetal assessment in Latvia: Overview of past research and future perspectives. *Journal of Baltic Studies* 24, 223–233.

Balodis, V.G., Brumelis, K., Kalviskis, O., Nikodemus, D.Y., and Tjarve, V.Z. (1996). Does the Skrunda radio location station diminish the radial growth of pine trees? *The Science of the Total Environment* 180, 57–64.

Balzano, Q., and Sheppard, A. R. (2012). Comments on the article entitled "Review of possible modulation-dependent biological effects of radiofrequency fields" by Juutilainen et al. *Bioelectromagnetics* 33, 710–711.

Barnett, K. C., Clay, C. E., and Clegg, F. G. (1977). Congenital nuclear cataracts in cattle. *Veterinary Record* 100, 505–508.

Beaubois, E., Girard, S., Lallechere, S., Davies, E., Paladian, F., Bonnet, P., Ledoigt, G., and Vian, A. (2007). Intercellular communication in plants: evidence for two rapidly transmitted systemic signals generated in response to electromagnetic field stimulation in tomato. *Plant Cell & Environment* 30, 834–844.

Beers, G. J. (1989). Biological effects of weak electromagnetic fields from 0 Hz to 200 MHz: a survey of the literature with special emphasis on possible magnetic resonance effects. *Magnetic Resonance Imaging* 7, 309–331.

Berger, K. (2007). Where have all the bees gone? Blame people, not cellphones. http://www.seattlepi.com/local/opinion/article/Where-have-all-the-bees-gone-Blame-people-not-1242972.php. Accessed 06/07/2012.

Bigu-del-Blanco, J., and Romero-Sierra, C. (1975a). The properties of bird feathers as converse piezoelectric transducers and as receptors of microwave radiation. I. Bird feathers as converse piezoelectric transducers. *Biotelemetry* 2, 341–353.

Bigu-del-Blanco, J., and Romero-Sierra, C. (1975b). The properties of bird feathers as converse piezoelectric transducers and as receptors of microwave radiation. II. Bird feathers as dielectric receptors of microwave radiation. *Biotelemetry* 2, 354–364.

Bindokas, V. P., Gauger, J. R., and Greenberg, B. (1988). Mechanism 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.

Brodie, G., Ryan, C., and Lancaster, C. (2012a). The effect of microwave radiation on prickly paddy melon (*Cucumis myriocarpus*) *International Journal of Agronomy* 2012. Article ID 287608, 1–10.

Brodie, G., Ryan, C., Lancaster, C., and Cousens, R. (2012b). Microwave technologies as part of an integrated weed management strategy: A review. *International Journal of Agronomy* 2012. Article ID 636905, 1–14.

Bruderer, B., and Boldt, A. (1994). Homing pigeons under radio influence. *Naturwissenschaften* 81, 316–317.

Byman, D., Battista, S. P., Wasserman, F. E., and Kunz, T. H. (1985). Effect of microwave irradiation (2.45 GHz, CW) on egg weight loss, egg hatchability, and hatchling growth of the Coturnix quail. *Bioelectromagnetics* 6, 271–282.

Cammaerts, M. C., De Doncker, P., Patris, X., Bellens, F., Rachidi, Z., and Cammaerts, D. (2012). GSM 900 MHz radiation inhibits ants' association between food sites and encountered cues. *Electromagnetic Biology and Medicine* 31, 151–165.

Carstensen, E. L. (1987). *Biological effects of transmission line fields*. New York, NY: Elsevier.

CCD Working Group. (2006). *Colony Collapse Disorder Preliminary Report*. In Mid-Atlantic Apiculture Research and Extension Consortium (MAAREC), pp. 1–22.

CCD Working Group. (2010). *Colony Collapse Disorder, Progress Report. CCD Steering Committee*. http://www.ars.usda.gov/is/br/ccd/ccdprogressreport2010.pdf. Accessed 06/07/2012.

Chavdoula, D. E., Panagopoulos, D. J., and Margaritis, L. H. (2010). Comparison of biological effects between continuous and intermittent exposure to GSM-900-MHz mobile phone radiation: Detection of apoptotic cell-death features. *Mutation Research* 700, 51–61.

Diprose, M. F., Benson, F. A., and Willis, A. J. (1984). The effect of externally applied electrostatic fields, microwave radiation and electric currents on plants and other organisms, with special reference to weed control. *The Botanical Review* 50, 171–223.

Douglas, I. (2010). Mobile phones and bees: shoddy research helps no one. http://blogs.telegraph.co.uk/technology/iandouglas/100005223/mobile-phones-and-bees-shoddy-research-helps-helps-no-one/. Accessed 06/07/2012.

Duan, J. J., Marvier, M., Huesing, J., Dively, G., and Huang, Z. Y. (2008). A meta-analysis of effects of Bt crops on honey bees (Hymenoptera: Apidae). *PloS ONE* 3(1), e1415.

Everaert, J., and 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, 63–72.

Favre, D. (2011). Mobile phone-induced honeybee worker piping. *Apidologie* 42, 270–279.

Frankel, R. B. (1984). Magnetic guidance of organisms. *Annual Review Biophysics Bioengineering* l3, 85–103.

Free, J. B. (1993). *Insect pollination of crops*. London: Academic Press.

Frier, H. J., Edwards, E., Smith, C., Neale, S., and Collett, T. S. (1996). Magnetic compass cues and visual pattern learning in honeybees. *The Journal of Experimental Biology* 199, 1353–1361.

Gary, N. E., and Westerdahl B. B. (1981). Flight, orientation, and homing abilities of honeybees following exposure to 2.45-GHz CW microwaves. *Bioelectromagnetics* 2, 71–75.

Gildersleeve, R. P., Galvin, M. J., McRee, D. I., Thaxton, J.P., and Parkhurst, C.R. (1987). Reproduction of Japanese quail after microwave irradiation (2.45 GHz CW) during embryogeny. *Bioelectromagnetics* 8, 9–21.

Guzmán-Novoa, E., Eccles, L., Calvete, V., McGowan, J., Kelly, P. G., and Correa-Benítez, A. (2010). *Varroa destructor* is the main culprit for the death and reduced populations of overwintered honey bee (*Apis mellifera*) colonies in Ontario, Canada. *Apidologie* 41, 443–450.

Hamnerius, Y., Olofsson, H., Rasmuson, A., and Rasmuson, B. (1979). A negative test for mutagenic action of microwave radiation in *Drosophila melanogaster*. *Mutation Research* 68, 217–223.

Hamnerius, Y., Rasmuson, A., and Rasmuson, B. (1985). Biological effects of high-frequency electromagnetic fields on *Salmonella typhimurium* and *Drosophila melanogaster*. *Bioelectromagnetics* 6, 405–414.

Hamrick, P. E., and McRee, D. I. (1975). Exposure of the Japanese Quail embryo to 2.45 GHz microwave radiation during the second day of development. *Journal of Microwave Power* 10, 211–221.

Hamrick, P. E., and McRee, D. I. (1980). The effect of 2450 MHz microwave irradiation on the heart rate of embryonic quail. *Health Physics* 38, 261–268.

Harst, W., Kuhn, J., and 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, 1–6.

Hässig, M., Jud, F., Nägeli, H., Kupper, J., and Spiess, M. M. (2009). Prevalence of nuclear cataract in Swiss veal calves and its possible association with mobile telefon antenna base stations (in German). *Schweizer Archiv Fur Tierheilkunde* 151, 471–478.

Hässig, M., Jud, F., and Spiess, B. (2012). Increased occurrence of nuclear cataract in the calf after erection of a mobile phone base station (in German). *Schweizer Archiv Fur Tierheilkunde* 15, 82–86.

Haubrugge, E., Nguyen, B. K., Widart, J., Thomé, J.-P., Fickers, P., and Depauw, E. (2006). Le dépérissement de l'abeille domestique, *Apis mellifera* L., 1758 (Hymenoptera: Apidae): faits et causes probables. *Notes fauniques de Gembloux* 59, 3–21.

Heynick, L. N., and Merritt, J. H. (2003). Radiofrequency fields and teratogenesis. *Bioelectromagnetics* Suppl 6, S174–S186.

Higes, M, Martín-Hernández, R., Garrido-Bailón, E., González-Porto, A. V., García-Palencia, P., Meana, A., Del Nozal, M. J., Mayo, R., and Bernal, J. L. (2009). Honeybee colony collapse due to *Nosema ceranae* in professional apiaries. *Environmental Microbiology Reports* 1, 110–113.

IARC. (2002). *IARC monograph 80. Non-ionizing radiation, part I: Static and extremely low-frequency (ELF) electric and magnetic fields*. IARC Press: Lyon.

IARC. (2012, in press). *IARC monograph 102. Non-ionizing radiation, Part II: Radiofrequency Electromagnetic Fields [includes mobile telephones]*. IARC Press: Lyon.

ICNIRP. (1998). Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). *Health Physics* 74, 494–522.

ICNIRP. (2009). ICNIRP statement on the "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). *Health Physics* 97, 257–259.

Johnson, R. M., Ellis, M. D., Mullin, C. A., and Frazier, M. (2010). Pesticides and honey bee toxicity—USA. *Apidologie* 41, 312–331.

Jonas, H. (1983). Responses of maize seedlings to microwave irradiation. *Environmental Pollution – Series B* 6, 207–219.

Joos, K., Masumy, S., Schweingruber, F. H., and Stäger, C. (1988). Untersuchung über möglishe Einflüsse hochfrequenter elektromagnetischer Wellen auf den Wald. *Technische Mitteilungen PTT* 1/1988, 2–11.

Juutilainen, J. (2005). Developmental effects of electromagnetic fields. *Bioelectromagnetics* 26 (Suppl 7), S107–S115.

Juutilainen, J., Lagroye, I., Miyakoshi, J., van Rongen, E., Saunders, R., de Seze, R., Tenforde, T., Verschaeve, L., Veyret, B., and Xu, Z. (2009). Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz – 300 GHz). In P. Vecchia, R. Matthes, G. Ziegelberger, J. Lin, R. Saunders, and A. Swerdlow (Eds.), *Review of experimental studies of RF biological effects (100 kHz – 300 GHz)*, ICNIRP: Munich, Germany 16/2009, ISBN 978-3-934994-10-2, pp. 90–303.

Juutilainen, J., Höytö, A., Kumlin, T., and Naarala, J. (2011). Review of possible modulation-dependent biological effects of radiofrequency fields. *Bioelectromagnetics*. 32, 511–34.

Juutilainen, J., Lagroye, I., Miyakoshi, J., van Rongen, E., Saunders, R., de Seze, R., Tenforde, T., Verschaeve, L., Veyret, B., and Xu, Z. (2011). Experimental studies on carcinogenicity of radiofrequency radiation. *Critical Reviews in Environmental Science and Technology* 41, 1664–1695.

Khalafallah, A. A., and Sallam, S. M. (2009). Response of maize seedlings to microwaves at 945 MHz. *Romanian Journal of Biophysics* 19, 49–62.

Kerlinger, P. (2000). Avian mortality at communication towers: A review of recent literature, research and methodology. Report prepared for the Prepared for the United States Fish and Wildlife Service, Office of Migratory Bird Management. Curry & Kerlinger, L.L.C., P.O. Box 453, Cape May Point, NJ 08212. http://library.fws.gov/Pubs9/avian_mortality00.pdf. Accessed 10/07/2012.

Kimmel, S., Kuhn, J., Harst, W., and Stever, H. (2007). Electromagnetic radiation: influences on honeybees (*Apis mellifera*). *IIAS – InterSymp Conference*, Baden-Baden, 1–6.

Kirschvink, J. L., Padmanabha, S., Boyce, C. K.,and Oglesby, J. (1997). Measurement of the threshold sensitivity of honeybees to weak, extremely low-frequency magnetic fields. *Journal of Experimental Biology* 200, 1363–1368.

Kirschvink, J. L., and Walker, M. M. (1995). Honeybees and magnetoreception. *Science* 269, 1889.

Kowalczuk, C., Yarwood, G., Blackwell, R., Priestner, M., Sienkiewicz, Z., Bouffler, S., Ahmed, I., Abd-Alhameed, R., Excell, P., Hodzic, V., Davis, C., Gammon, R., and Balzano, Q. (2010). Absence of nonlinear responses in cells and tissues exposed to RF energy at mobile phone frequencies using a double resonant cavity. *Bioelectromagnetics* 31, 556–66.

Kramar, P. O., Emery, A. F., Guy, A. W., and Lin, J. C. (1975). The ocular effects of microwaves on hyperthermic rabbits: A study of microwave cataractogenic mechanisms. *Annals of the New York Academy of Sciences* 247, 155–165.

Kremer, F., Poglitsch, A., Santo, L., Sperber, D., and Genzel, I. (1985). The influence of low-intensity millimeter-wave radiation on the growth of cress roots. *Zeitschrift für Naturforschung* 40c, 336–343.

Krewski, D., Glickman, B. W., Habsh, R. W. Y., Habbick, B., Lotz, W. G., Mandeville, R., Prato, F. S., Salem, T., and Weaver, D. F. (2007). Recent advances in research on radiofrequency fields and health: 2001–2003. *Journal of Toxicology and Environmental Health, Part B* 10, 287–318.

Krug, E. (1990). Pollenkeimung unter Einfluss electromagnetischer Wellen und Felder. *European Journal of Forest Pathology* 20, 251–255.

Kumar, N. R., Sangwan, S., and Badotra, P. (2011). Exposure to cell phone radiations produces biochemical changes in worker honey bees. *Toxicology International* 18, 70–72.

Kwan-Hoong, N. (2003). Non-ionizing radiations–sources, biological effects, emissions and exposures. *Proceedings of the International Conference on Non-Ionizing Radiation at UNITEN (ICNIR2003) Electromagnetic Fields and Our Health*, 20th–22nd October 2003. http://www.who.int/peh-emf/meetings/archive/en/keynote3ng.pdf. Accessed 06/07/2012.

Leonard, A., Berteaud, A. J., and Bruyere, A. (1983). An evaluation of the mutagenic, carcinogenic and teratogenic potential of microwaves. *Mutation Research* 123, 31–46.

Liddle, C. G., Putnam, J. P., Lewter, O. L., Lewis, J. Y., Bell, B., West, M. W., and Stead, A. (1986). Effect of 9.6-GHz pulsed microwaves on the orb web spinning ability of the cross spider (*Araneus diadematus*). *Bioelectromagnetics* 7, 101–105.

Löscher, W., and Käs, G. (1998). Conspicious behavioural abnormalities in a dairy cow herd near a TV and radio transmitting antenna. *Der Praktische Tierarzt* 79, 437–444.

Magras, I. N., and Xenos, T. D. (1997). RF radiation-induced changes in the prenatal development of mice. *Bioelectromagnetics* 18, 455–461.

Malone, L. A., and Pham-Delègue, M. H. (2001). Effects of transgene products on honey bees (*Apis mellifera*) and bumblebees (Bombus sp.). *Apidologie* 32, 287–304.

Marec, F., Ondrácek, J., and Brunnhofer, V. (1985). The effect of repeated microwave irradiation on the frequency of sex-linked recessive lethal mutations in *Drosophila melanogaster*. *Mutation Research* 157, 163–167.

Marvier, M., McCreedy, C., Regetz, J., and Kareiva, P. (2007). A meta-analysis of effects of Bt cotton and maize on non target invertebrates. *Science* 316, 1475–7.

McRee, D. I., and Hamrick, P. E. (1977). Exposure of Japanese quail embryos to 2.45-GHz microwave radiation during development. *Radiation Research* 71, 355–366.

McRee, D. I., Hamrick, P. E., Zinkl, J., Thaxton, P., and Parkhurst, C. R. (1975). Some effects of exposure of the Japanese quail embryo to 2.45-GHz microwave radiation. *Annals of the New York Academy of Sciences* 247, 377–390.

McRee, D. I., Thaxton, J. P., and Parkhurst, C. R. (1983). Reproduction in male Japanese quail exposed to microwave radiation during embryogeny. *Radiation Research* 96, 51–58.

Minkel, J. R. (2007). Mysterious honeybee disappearance linked to rare virus. *Science News (Scientific American)*, 09-07.

Mittler, S. (1976). Failure of 2- and 10-meter radio waves to induce genetic damage in *Drosophila melanogaster*. *Environmental Research* 11, 326–330.

Mittler, S. (1977). Failure of chronic exposure to nonthermal FM radio waves to mutate *Drosophila*. *Journal of Heredity* 68, 257–258.

Mixson, T. A., Abramson, C. I., Nolf, S. L., Johnson, G. A., Serrano, E., and Wells, H. (2009). Effect of GSM cellular phone radiation on the behavior of honey bees (Apis mellifera). *Science of Bee Culture* 1, 22–27.

Nicholls, B., and Racey, P. A. (2007). Bats avoid radar installations: could electromagnetic fields deter bats from colliding with wind turbines? *PloS One* 2, e297.

Nicholls, B., and Racey, P. A. (2009). The aversive effect of electromagnetic radiation on foraging bats: A possible means of discouraging bats from approaching wind turbines. *PloS One* 4, e6246.

Nittby, H., Moghadam, M. K., Sun, W., Malmgren, L., Eberhardt, J., Persson, B. R., and Salford, L. G. (2012). Analgetic effects of non-thermal GSM-1900 radiofrequency electromagnetic fields in the land snail *Helix pomatia*. *International Journal of Radiation Biology* 88, 245–252.

NRPB. (2004). Review of the scientific evidence for limiting exposure to electromagnetic fields (0-300 GHz). Documents of the NRPB, vol. 15, nr. 3, pp. 215.

O'Connor, M. E. (1999). Intrauterine effects in animals exposed to radiofrequency and microwave fields. *Teratology* 59, 287–291.

Oldroyd, B. P. (2007). What's killing American honey bees? *PloS Biology* 5(6), e168.

Panagopoulos, D. J. (2012). Effect of microwave exposure on the ovarian development of *Drosophila melanogaster*. *Cell Biochemistry and Biophysics* 63, 121–132.

Panagopoulos, D. J., Chavdoula, E. D., Karabarbounis, A., and Margaritis, L. H. (2007). Comparison of bioactivity between 900 MHz and DCS1800 MHz mobile telephony radiation. *Electromagnetic Biology and Medicine* 26, 33–44.

Panagopoulos, D. J., Chavdoula, E. D., and Margaritis, L. H.. (2010). Bioeffects of mobile telephony radiation in relation to its intensity or distance from the antenna. *International Journal of Radiation Biology* 86, 345–357.

Panagopoulos, D. J., Karabarbounis, A., and Margaritis, L. H. (2004). Effects of GSM 900-MHz mobile phone radiation on the reproductive capacity of *Drosophila melanogaster*. *Electromagnetic Biology and Medicine* 23, 29–43.

Panagopoulos, D. J., and Margaritis, L. H. (2008). Mobile telephony radiation effects on living organisms. In A.C. Harper and R.V. Buress (Eds.), *Mobile telephones: Networks, applications, and performance* (pp. 107–149). Nova Science Publishers: New York.

Ratnieks, L. W., and Carreck, N. L. (2010). Clarity on honey bee collaps. *Science* 327, 152–153.

Rejt, L., Mazgajski, T., Kubacki, R., Kieliszek, J., Sobiczewska, E., and Szmigielski, S. (2007). Influence of radar radiation on breeding biology of tits (Parus sp.). *Electromagnetic Biology and Medicine* 26, 235–238.

Repacholi, M. H., and Cardis, E. (1997). Criteria for EMF health risk assessment. *Radiation Protection Dosimetry* 72, 305–12.

Ritz, T., Wiltschko, R., Hore, P. J., Rodgers, C. T., Stapput, K., Thalau, P., Timmel, C. R., and Wiltschko, W. (2009). Magnetic compass of birds is based on a molecule with optimal directional sensitivity. *Biophysical Journal* 96, 3451–3457.

Roux, D., Faure, C., Bonnet, P., Girard, S., Ledoigt, G., Davies, E., Gendraud, M., Paladian, F., and Vian, A. (2008a). A possible role for extra-cellular ATP in plant responses to high frequency, low amplitude electromagnetic field. *Plant Signaling and Behavior* 3, 383–385.

Roux, D., Vian, A., Girard, S., Bonnet, P., Paladian, F., Davies, E., and Ledoigt, G. (2006). Electromagnetic fields (900 MHz) evoke consistent molecular responses in tomato plants. *Physiologia Plantarum* 128, 283–288.

Roux, D., Vian, A., Girard, S., Bonnet, P., Paladian, F., Davies, E., and Ledoigt, G. (2008b). High frequency (900 MHz) low amplitude (5 V m^{-1}) electromagnetic field: A genuine environmental stimulus that affects transcription, translation, calcium and energy charge in tomato. *Planta* 227, 883–891.

Sanudeen Sahib, S. (2011a). Electromagnetic radiation (EMR) clashes with honey bees. *International Journal of Environmental Sciences* 1, 897–900.

Sanudeen Sahib, S. (2011b). Impact of mobile phones on the density of honeybees. *Journal of Public Administration and Policy Research* 3, 131–133.

SCENIHR (Scientific Committee on Emerging and Newly Identified Health Risks). (2009). Health effects of exposure to EMF. In *European Commission, Directorate-General for Health and Consumers*, pp. 1–83.

SCENIHR (Scientific Committee on Emerging and Newly Identified Health Risks). (2012). Memorandum on the use of the scientific literature for human health risk assessment purposes – weighing of evidence and expression of uncertainty.

Schmutz, P., Siegenthaler, J., Stäger, C., Tarjan, D., and 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.

Selga, T., and Selga, M. (1996). Response of *Pinus sylvestris* L. needles to electromagnetic fields. Cytological and ultrastructural aspects. *The Science of the Total Environment* 180, 65–73.

Sharma, V. P., and Kumar, N. R. (2010). Changes in honeybee behaviour and biology under the influence of cellphone radiations. *Current Science* 98, 1376–1378.

Sharpe, R. J., and Heyden, L. C. (2010). Honey bee colony collapse disorder is possibly caused by a dietary pyrethrum deficiency. *Bioscience Hypotheses* 2, 439–440.

Singh, R, Levitt, A. L., Rajotte, E. G., Holmes, E. C., Ostiguy, N., van Engelsdorp, D., Lipkin, W. I., dePamhilis, C. W., Toth, A. L., and Cox-Foster, D. L. (2010). RNA viruses in hymenopteran pollinators: Evidence of inter-taxa virus transmission via pollen and potential impact on non-apis hymenopteran species. *PloS ONE* 5, e14357.

Stäger, C. (1989). Felduntersuchung über eventuelle Schadenwirkungen von Mikrowellenfeldern auf den Wald. *Technische Mitteilungen PTT* 12/1989, 517–526.

Stärk, K. D. C., Altpeter, E., Manz, B., Griot, C., and Abelin, T. (1997). Absence of chronic effect of exposure to short-wave radio broadcast signal on salivary melatonin concentrations in dairy cattle. *Journal of Pineal Research* 22, 171–176.

Stindl, R., and Stindl, W., Jr. (2010). Vanishing honey bees: is the dying of adult worker bees a consequence of short telomeres and premature aging? *Medical Hypotheses* 75, 387–390.

Tafforeau, M., Verdus, M.-C., Norris, V., White, G., Demarty, M., Thellier, M., and Ripoll, C. (2002). SIMS study of the calcium-deprivation step related to epidermal meristem production induced in flax by cold shock or radiation from a GSM telephone. *Journal of Trace and Microprobe Techniques* 20, 611–23.

Tafforeau, M., Verdus, M. C., Norris, V., White, G. J., Cole, M., Demarty, M., Thellier, M., and Ripoll, C. (2004). Plant sensitivity to low intensity 105 GHz electromagnetic radiation. *Bioelectromagnetics* 25, 403–407.

Tafforeau, M., Verdus, M. C., Norris, V., Ripoll, C., and Thellier, M. (2006). Memory process in the response of plants to environmental signals. *Plant Signaling and Behavior* 1, 9–14.

Thalau, P., Ritz, T., Stapput, K., Wiltschko, R., and Wiltschko, W. (2005). Magnetic compass orientation of migratory birds in the presence of a 1.315 MHz oscillating field. *Naturwissenschaften* 92, 86–90.

Urech, M., Eicher, B., and Siegenthaler, J. (1996). Effects of microwave and radio frequency electromagnetic fields on lichens. *Bioelectromagnetics* 17, 327–334.

Urech, M., and Herzig, R. (1990). Einfluss elektromagnetischer Felder auf Flechten-Transplantate, *puls consulting, Mhlemattstr.* 31, CH-3007 Berne, Switzerland: Bericht zum Expositionsversuch 1990,

Ursache, M., Mindru, G., Creanga, D. E., Tufescu, F. M., and Groiceanu, C. (2009). The effects of high frequency electromagnetic waves on the vegetal organisms. *Romanian Journal of Physics* 54, 133–145.

Vácha, M., Půžová, T., and Kvičalová, M. (2009). Radio frequency magnetic fields disrupt magnetoreception in American cockroach. *The Journal of Experimental Biology* 212, 3473–3477.

Van Der Zee, R., Pisa, L., Andonov, S., Brodschneider, R., Charrière, J. -D., Chlebo, R., Coffey, M. F., Crailsheim, K., Dahle, B., Gajda, A., Gray, A., Drazic, M. M., Higes, M., Kauko, L., Kence, A., Kence, M., Kezic, N., Kiprijanovska, H., Kralj, J., Kristiansen, P., Hernandez, R. M., Mutinelli, F., Nguyen, B. K., Otten, C., Özkirim, A., Pernal, S. F., Peterson, M., Ramsay, G., Santrac, V., Soroker, V., Topolska, G., Uzunov, A., Vejsnæs, F., Wei, S., and Wilkins, S. (2012). Managed honey bee colony losses in Canada, China, Europe, Israel and Turkey, for the winters of 2008-9 and 2009-10. *Journal of Apicultural Research* 51, 100–104.

van Engelsdorp, D., Evans, J. D., Saegerman, C., Mullin, C., Haubruge, E., Kim Nguyen, B., Frazier, M., Frazier, J., Cox-Foster, D., Chen, Y., Underwood, R., Tarpy, D. R., and Pettis, J. S. (2009). Colony collapse disorder: A descriptive study. *PloS ONE* 4(8), e6481.

van Rongen, E., Saunders, R., Croft, R., Juutilainen, J., Lagroye, I., Miyakoshi, J., de Seze, R., Tenforde, T., Verschaeve, L., Veyret, B., and Xu, Z. (2009). Effects of radiofrequency electromagnetic fields on the human nervous system. *Journal of Toxicology and Environmental Health Part B Critical Reviews* 12, 572–597.

Verschaeve, L. (1995). Can non-ionizing radiation induce cancer? *Cancer Journal* 8, 237–249.

Verschaeve, L. (2012). Chapter 20: Evaluations of international expert group reports on the biological effects of radiofrequency fields. In: E. Ali (Ed.), *Wireless communications* (pp. 523–546). ISBN: 978-953-51-0189-5, InTech, DOI: 10.5772/37762. INTECH Publ.

Verschaeve, L., Juutilainen, J., Lagroye, I., Miyakoshi, J., Saunders, R., de Seze, R., Tenforde, T., van Rongen, E., Veyret, B., and Xu, Z. (2010). In vitro and in vivo genotoxicity of radiofrequency fields. *Mutation Research* 705, 252–268.

Verschaeve, L., and Maes, A. (1998). Genetic, carcinogenic and teratogenic effects of radiofrequency fields. *Mutation Research* 410, 141–165.

Vian, A., Faure, C., Girard, S., Davies, E., Hallé, F., Bonnet, P., Ledoigt, G., and Paladian, F. (2007). YES, Plants do respond to GSM-like radiations!!! *Plant Signaling and Behavior* 2, e1–e3.

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

Vignal, R., Crouzier, D., Dabouis, V., and Debouzy, J. -C. (2009). Effects of mobile phones and radar radiofrequencies on the eye (in French). *Pathologie Biologie* 57, 503–508.

Walker, M. M., and Bitterman, M. E. (1989). Honeybees can be trained to respond to very small changes in geomagnetic field intensity. *Journal of Experimental Biology* 145, 489–494.

Warnke, U. (2009). Bees, birds and mankind. Destroying nature by 'electrosmog'. In *Effects of wireless communication technologies, A brochure series by the Competence Initiative for the protection of humanity, Environment and Democracy, Oppenheimer & Son and the Diamond Route*, 1–46.

Wasserman, F. E., Dowd, C., Byman, D., Schlinger, B. A., Battista, S. P., and Kunz, T. H. (1984b). Aversion/attraction of blue jays to microwave irradiation. *Physiology and Behavior* 33, 805–807.

Wasserman, F. E., Dowd, C., Schlinger, B. A., Byman, D., Battista, S. P., and Kunz, T. H. (1984a). The effects of microwave radiation on avian dominance behavior. *Bioelectromagnetics* 5, 331–339.

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

WHO. (1993). *Electromagnetic fields (300 Hz-300GHz). Environmental health Criteria 137*. Geneva: Author.