Science of the Total Environment 543 (2016) 662–669

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

Radiotelemetry and wildlife: Highlighting a gap in the knowledge on radiofrequency radiation effects

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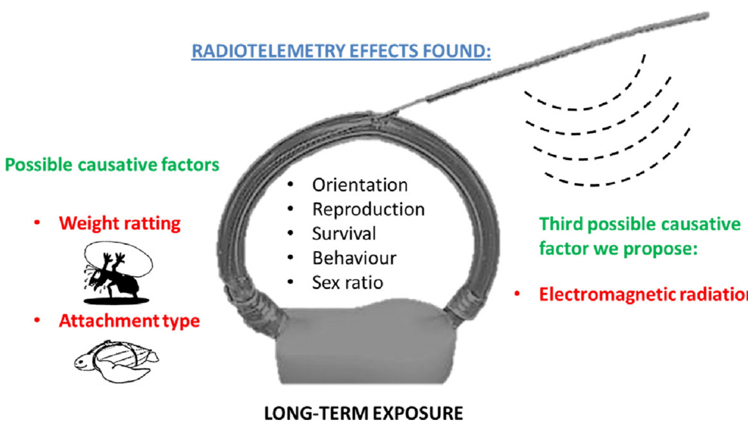
HIGHLIGHTS

- Radiotracking may induce negative effects that can bias the results.
- Effects have been documented on survival, reproduction and behaviour.
- The only causative factors considered were the weight and the attachment type.
- Radiofrequency radiation (RFR) has not been considered to date.
- The possibility that RFR may be responsible should be investigated.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 September 2015
Received in revised form 13 November 2015
Accepted 14 November 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Long-term effects
Orientation
Reproduction
Survival
Tracking
Transmitters

ABSTRACT

Radio transmitters and associated devices may induce negative effects that can bias the results of ongoing research. The main documented effects of radio transmitters on animals include reduced survival, decreased productivity, changes in behaviour and movement patterns and a biased sex ratio. The only factors that have claimed responsibility for these possible damages are the weight of the radio transmitter and associated devices, and the attachment type. The electromagnetic radiation produced by radio transmitters has not been considered so far in research. There have been no studies evaluating the effects of non-ionising electromagnetic radiation (radiofrequency signals) necessary for tracking, although the problems found were significantly associated with the length of time that animals had been carrying their radio transmitters. Similar problems as those in radiotracked animals have been found in numerous studies with animals exposed to radiofrequency radiation for a sufficient amount of time. Laboratory scientists investigating the orientation of animals know they have to shield the place where experiments are performed to prevent interference from man-made radiation, as anthropogenic signals may distort the results. It is paradoxical that, at the same time, field scientists investigating the movements and other aspects of animal biology are providing animals with radio transmitters that emit the same type of radiation, since this may affect the results concerning their orientation and movement. This paper identifies gaps in the knowledge that should be investigated in-depth. The possibility that the radiofrequency radiation from radiotracking devices is responsible for the findings should be considered. Considering this factor may allow researchers to best understand the long-term effects found.

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http://dx.doi.org/10.1016/j.scitotenv.2015.11.073

Contents

1. Introduction

Radiotelemetry is a technique used to determine information about an animal using radio signals (Mech and Barber, 2002). It has been used to study ecology, behaviour, habitat selection, population dynamics, resource use, home range, dispersal and migration patterns in all types of free-ranging wild vertebrates (McCleave and Stred, 1975; Murray and Fuller, 2000; Withey et al., 2001; Mech and Barber, 2002; Cagnacci et al., 2010; Gitzen et al., 2013; Vandenabeele, 2013; O'Mara et al., 2014; Habib et al., 2014).

Radio transmitters have experienced continuous technological improvement (Barron et al., 2010; Dixon, 2011). As technology has progressed, three types of models are generally considered: (1) very high frequency (VHF) radio tracking, (2) satellite tracking, and (3) Global Positioning System (GPS) tracking (see review in Mech and Barber, 2002; Cagnacci et al., 2010). GPS transmitters powered by solar cells make longer periods of transmission are now available for birds. More advanced systems of satellite telemetry utilise a platform transmitter terminal (PTT) working with radiofrequency radiation (401 MHz) and must be powerful enough to transmit a signal to satellites (Mech and Barber, 2002).

Radio-tracking or wildlife telemetry have stimulated rapid conceptual advances; as a result, new opportunities have arisen due to technical and analytical challenges, which have revolutionised wildlife research (Mech and Barber, 2002; Cagnacci et al., 2010). However, these undoubted advantages sometimes overshadow the potential drawbacks (adverse effects) and, generally, previous studies were not designed specifically to evaluate the impact of radiotracking (McIntyre, 2012).

Although some studies have found no effects (Rae et al., 2009; Gow et al., 2011; Therrien et al., 2012), radio-tracking may have physiological and behavioural effects which can harm the animal health or wellbeing and even distort the results, making any conclusions less valid. The adverse effects can range from short to long-term and from tolerable to severe or even deadly (Mech and Barber, 2002; Dixon, 2011). For that reason, following the initial euphoria (Cagnacci et al., 2010), this assumption should be rigorously tested. It is important that investigators begin to consider, document and evaluate such negative effects, which can lead to the development of essential recommendations regarding best practices (Hooge, 1991; Gervais et al., 2006; Steenhof et al., 2006; Chipman et al., 2007; Casper, 2009; Barron et al., 2010; Booms et al., 2011; Peniche et al., 2011; Vandenabeele, 2013; O'Mara et al., 2014; Kesler et al., 2014).

2. Radiotelemetry effects found

The main documented effects of radio transmitters on animals include reduced survival, decreased productivity, changes in behaviour and movement patterns and biased sex ratios. Barron et al. (2010) conducted a rigorous meta-analysis based on 84 studies using radio-tracking in birds; they found that transmitters and the devices associated induced significant negative effects that may have biased resulting data, adversely affecting every aspect considered except flying ability.

A fundamental assumption in the survival estimation from radiotelemetry data is that animals with radio transmitters have the same survival probability as animals that are not radiomarked (McIntyre, 2012). Some studies have shown that survival is not influenced by radiomarking (Hiraldo et al., 1994; Berdeen and Otis, 2006). However, several others have shown that radio transmitters can significantly lower annual survival rates (Paton et al., 1991; Cotter and Gratto, 1995; Withey et al., 2001; Steenhof et al., 2006; Chipman et al., 2007; Gervais et al., 2006; McIntyre, 2012). Therefore, any estimates of survival based on radiomarked birds may be biased downward and should be viewed with caution (Steenhof et al., 2006).

Further, although some studies have found no effects on productivity (Hiraldo et al., 1994; Conway and Garcia, 2005), radio transmitters can alter reproductive rates (Paton et al., 1991; Pietz et al., 1993; Withey et al., 2001; Tuyttens et al., 2002; Demers et al., 2003; Steenhof et al., 2006; Chipman et al., 2007; Barron et al., 2010; Peniche et al., 2011).

Radio transmitters and their attachments may alter the behaviour and activity of birds (Withey et al., 2001; Steenhof et al., 2006; Gervais et al., 2006; Chipman et al., 2007; Booms et al., 2011) in terms of feeding behaviour (Pietz et al., 1993; Barron et al., 2010) and mobility (McIntyre, 2012). Some studies have not detected changes in behaviour (Hiraldo et al., 1994), while others have detected problems during only the first few days after radio-tracking (Glahder et al., 1997), which is due to the stress of capture. Transmitter equipped birds showed acute elevated faecal glucocorticoid levels, which returned to normal within 48 h. (Suedkamp Wells et al., 2003).

Finally, Moorhouse and Macdonald (2005) found that the radio-collaring of female water voles (*Arvicola terrestris*) caused male-skewed (43:13) sex ratios in offspring born to this population.

3. Factors that have been attributed to the effects found

3.1. Weight rating

The first and most important factor that has claimed responsibility for possible damages is the weight of the radio transmitter and associated devices. Researchers studying the effects of radiomarking birds have been primarily concerned with the radio transmitter/body weight ratio, which is used as a basis for advising on safe use (Hooge, 1991; Murray and Fuller, 2000; Naef-Daenzer et al., 2001; Mech and Barber, 2002; Peniche et al., 2011; O'Mara et al., 2014). It is recommended that the total radio transmitter and associated devices should not exceed 2–5% of the bodyweight (Peniche et al., 2011).

Some authors argue that these guidelines are arbitrary because they were not based on experimental data (Steenhof et al., 2006). In fact, despite the wide acceptance of the '5% rule', a rigorous meta-analysis by Barron et al. (2010) found little evidence that negative effects for most aspects of behaviour and ecology increased as transmitters became proportionally heavier. Transmitter burden did not contribute significantly in explaining the negative effects (Steenhof et al., 2006), and even birds with proportionally heavier devices had higher nest success and survival rates (Barron et al., 2010). The effects on productivity can hardly be attributable to the weight of the device; therefore, there must be other factors that have not been considered.

3.2. Type of attachment

The second factor that has been taken into account when assessing damages is the type of attachment of the device. Attachment methods for different groups of vertebrates were reviewed in Mech and Barber (2002), and some authors have studied the effects of different types of harness (Bedrosian and Craighead, 2007; O'Mara et al., 2014); results showed that various types of attachments might have severe effects such as impaired survival, altered behaviour and a lower reproductive rate (Pietz et al., 1993; Withey et al., 2001; Gervais et al., 2006; Steenhof et al., 2006; Dixon, 2011; Peniche et al., 2011). Several authors agree that the back-mounted, harness-attached transmitters may cause pathological lesions (Peniche et al., 2011) and bias data of behaviour, productivity and survival. Consequently, researchers suggest that this type of attachment should not be used (Paton et al., 1991; Rotella et al., 1993; Gammonley and Kelley, 1994; Ward and Flint, 1995). Nevertheless, a rigorous meta-analysis showed that attachment type did not influence the proportion of studies reporting physical harm, although the proportion of studies reporting device-induced mortality differed among attachment types (Barron et al., 2010). Mortality was most commonly reported in studies using anchors, followed by implants, harnesses, collars and glue (Barron et al., 2010), with no mortality reported in studies using tail mounts (Hiraldo et al., 1994; Noel et al., 2013).

4. The importance of considering time

Studies that found no adverse effects usually only ran for a few weeks to a year (Hiraldo et al., 1994; Bedrosian and Craighead, 2007; Naef-Daenzer et al., 2001; Conway and Garcia, 2005; Berdeen and Otis, 2006; Davis et al., 2008). No studies have carefully evaluated the cumulative and long-term effects of radio-tracking (McIntyre, 2012); there is no reliable data regarding the long-term effects of radiomarking on the health of birds (Berdeen and Otis, 2006) because animals were not tracked for long enough periods to observe effects (Steenhof et al., 2006; Dixon, 2011).

Generally, the damage found in radiomarked birds is long-term, and the presence of pathological lesions was significantly associated with the length of time that birds had been carrying their radio transmitters (Dixon, 2011; Peniche et al., 2011). Adverse effects are slight, but birds that shed their transmitters increased their probability of survival (Steenhof et al., 2006). Unfortunately, Barron et al. (2010) did not consider the time during which the radio transmitter was attached to the animal in their meta-analysis, but concluded that there was no mortality reported in studies using tail mounts (which are detached during moulting, spend less time on the bird, and are farthest from vital organs).

4.1. A third factor that is not being considered

The frequencies usually used in wildlife telemetry range from 27 to 401 MHz (Mech and Barber, 2002). To the best of our knowledge, there have been no studies evaluating the effects of non-ionising electromagnetic radiation (radiofrequency radiation, RFR) from radio transmitters emitting the signals necessary for tracking. It would be important to investigate whether some problems found could be related to radiofrequency radiation, as this hypothesis has never been investigated (Fig. 1). The only reference on this topic found in the extensive literature reviewed notes that radio signals could have ill effects on the animals, although the radiated power from VHF transmitters is low enough (10 mW) that this possibility seems highly unlikely (Mech and Barber, 2002). The radiated power of PTTs used in more advanced systems of satellite telemetry is several orders higher (ranges from about 250 mW to 2 W), but there have been no findings of detrimental effects on the animals (Mech and Barber, 2002). Even in a recent doctoral thesis (Vandenabeele, 2013) that addresses the issue of the potentially negative impact of tracking devices on seabirds, this threat was not considered.

Barron et al. (2010) found no evidence that researchers have become better at reducing deleterious effects in most recent studies, although improved technology and lower the weight of the radio transmitters. Birds were similarly affected regardless of age, mode of locomotion and body mass (Barron et al., 2010).

Many of the studies conducted in captivity were done without radiofrequency radiation and did not consider this possible factor. For instance, no difference in blood parameters between transmitter attachment technique versus control groups were found in captive birds; however, in these studies, transmitters were non-functioning (Small et al., 2004; Small et al., 2005). Several other studies done in captivity found no effects on birds (Hernández et al., 2004; Pereia et al., 2009), but radiofrequency emissions were not explained in the methodology.

5. Studies on the effects of radio frequencies on living organisms

Radiofrequency radiation (RFR) is a form of electromagnetic field (EMF). Numerous studies on the effects of electromagnetic radiofrequency radiation (RFR) on living organisms warn of the danger of this type of radiation, as it can interfere mainly with the nervous, reproductive, endocrine and immune systems and is involved in numerous biological processes (Hyland, 2000 & Hyland, 2001). Recently it has been suggested that polarisation from man-made EMFs/EMR seems to be more bioactive than natural non-ionising EMFs/EMR and significantly increases the probability for the trigger initiation of biological/health effects (Panagopoulos et al., 2015). Most of the studies indicate that RFR can cause sublethal physiological disruptions such as those outlined below (summarised in Table 1).

5.1. Oxidative damage and free radicals

Experimental studies with electromagnetic field exposure in the radiofrequency (RF) range are related to changes in oxidant and antioxidant contents in animals, which induce different biological effects (Simkó, 2007; Yakymenko et al., 2014; Dasdag and Akdag, 2015). This radiation alters the activity of redox proteins in exposed cattle (Hässig et al., 2014). Among 100 currently available peer-reviewed studies that deal with the oxidative effects of low-intensity RFR, 93 confirmed

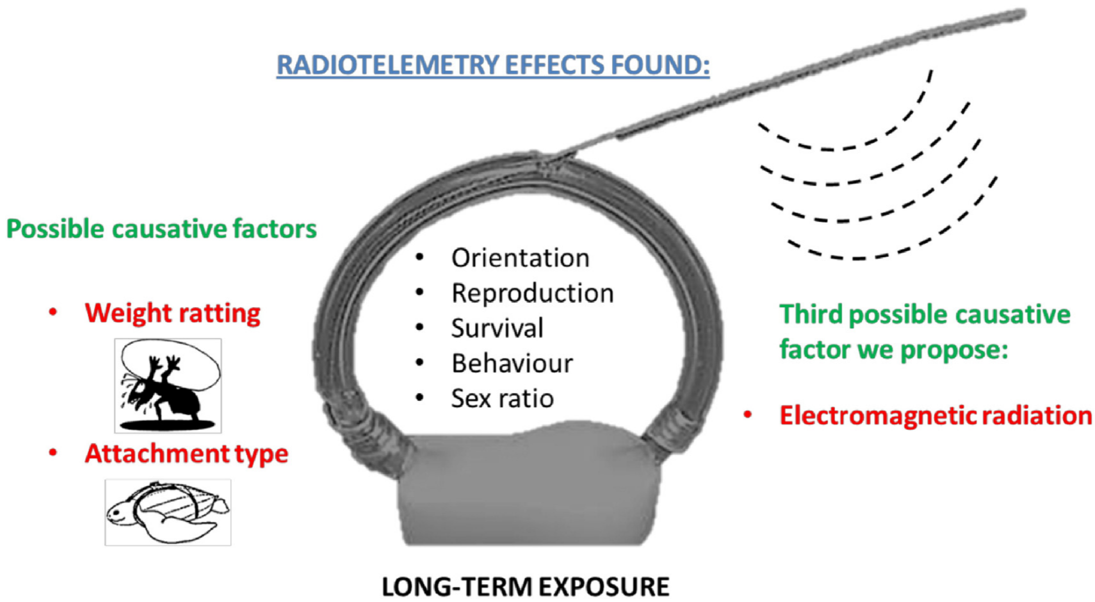

Fig. 1. Radiotelemetry effects found and possible causative factors.

that RFR induces oxidative effects in biological systems (Yakymenko et al., 2015). Radical scavengers/antioxidants might be involved in the effects of RFs (Belyaev, 2005). A link between exposure to electromagnetic fields and higher levels of oxidative stress is a contributor to ageing, neurodegenerative diseases, immune-system disorders and cancer (Fernie and Bird, 2001).

5.2. Stress proteins

Stress proteins are usually synthesised when cells are exposed to adverse environmental conditions, such as RF (cellular stress response), as has been shown in several studies conducted with electromagnetic field (EMF) exposure (Blank and Goodman, 2004). This effect of electromagnetic radiation has been called non-thermal shock (Tattersall et al., 2000; Shallom et al., 2002; Leszczynski et al., 2002; Weisbrot et al., 2003). In the case of devices used in radiotelemetry, since no detailed dosimetry study has been carried out and some of these devices emit relatively high intensity EM fields, thermal effects should not be discounted and therefore they should be called "low-intensity effects" (Levitt and Lai, 2010).

5.3. Calcium channels

Electromagnetic wave-range RF communication can affect the intercellular concentration and function of calcium channels (Dutta et al., 1989), producing an increased flow calcium in the brain of exposed rats (Paulraj et al., 1999). The modification of calcium channels caused by RF radiation is a process with significant consequences on animal physiology (Walleczek, 1992; Rao et al., 2008; Pall, 2013).

5.4. Immune system

Prolonged exposure to EMFs from transmitters can affect immune-system function by affecting biological processes, and a stressed immune system can increase the susceptibility of a bird or mammal to infectious diseases (Fernie and Bird, 2001). Effects on immune processes have also been described in exposed mice (Novoselova and Fesenko, 1998). Animal studies have reported immunological changes following exposure to EMFs, equivalent to those of wireless technologies (Boscol et al., 2001; Cleary et al., 1990 & Cleary et al., 1996).

5.5. Nervous system and behavioural effects

Various studies have documented the effects of RFR on the nervous system and cognitive function (Lai, 2014a), sleep (Pelletier et al., 2013) and electrical brain (EEG) response (Marino et al., 2003; Kramarenko and Tan, 2003; Ghosn et al., 2015). Radiofrequency radiation can produce a response in several types of neurons of the bird nervous system (Beasond and Semm, 2002).

Potential dangers arising from the prolonged and repeated exposure to non-ionising radiation in the long-term include cellular stress responses at low-intensity power levels that lead to an accumulation of DNA mutations and to the inhibition of cell apoptosis, and cause the increased permeability of the blood–brain barrier (Leszczynski et al., 2002; Di Carlo et al., 2002; Salford et al., 2003). The RF disease, or "Microwave syndrome", is a health problem in humans, which is caused by exposure to RF (Johnson-Liakouris, 1998; Gómez-Perretta et al., 2013). In a set of 211 published studies that analysed RF neurological effects: 144 publications (68%) demonstrated the effects on the nervous system, and 67 publications (32%) did not report any effect (Lai, 2014a).

5.6. Genotoxic effects and potential carcinogenicity

Radiofrequency radiation can cause genotoxic effects, which can lead also to cancer (Leszczynski et al., 2002; Gandhi and Singh, 2005). The significant increase in micronuclei in the erythrocytes of cattle grazing near transmitters has been interpreted as an indication of the genotoxic effect of exposure (Balode, 1996), and changes in cell proliferation as a result of RF exposure have also been described (Velizarov et al., 1999). A decrease in the survival of children with leukaemia near television antennae and a significantly reduced risk of leukaemia with increasing distance from the antennae of television (Hocking et al., 1996), or radio (Michelozzi et al., 1998) has been reported, as well as an increase in mortality due to neoplasia near cellular telephone base stations (Dode et al., 2011). Recent studies indicate that RFs can have carcinogenic effects on animals and humans (Tillmann et al., 2010; Coureau et al., 2014; Lerchl et al., 2015).

The current view is that electromagnetic fields might act as promoters and initiators of cancer; favouring their development, rather than directly inducing it. Recently (may 2011), an expert committee convened at the International Agency for Research on Cancer (IARC)

Table 1
Possible similarities between radiofrequency radiation effects and effects found in studies using radiotracking.

Documented effects	Studies on the effects of radio frequencies on living organisms			Radiotelemetry effects found		
	Effects type	Animal group	References	Effects type	Animal group	References
Oxidative damage stress proteins calcium channels immune system	Changes in oxidant and antioxidant contents. Stress protein synthesis, modification of calcium channels. Immune system effects	Various cell types in mammals, birds and humans	Simkó (2007); Yakymenko et al. (2014); Hässig et al. (2014); Yakymenko et al. (2015); Belyaev (2005); Fernie and Bird (2001); Blank and Goodman (2004); Tattersall et al. (2000); Shallom et al. (2002); Leszczynski et al. (2002); Weisbrot et al. (2003); Dutta et al. (1989); Paulraj et al. (1999); Walleczek (1992); Rao et al. (2008); Pall (2013); Novoselova and Fesenko (1998); Boscol et al. (2001); Cleary et al. (1990); Cleary et al. (1996)	Lower annual survival rates	Birds	Paton et al. (1991); Cotter and Gratto (1995); Withey et al. (2001); Steenhof et al. (2006); Chipman et al., 2007; Gervais et al. (2006); McIntyre (2012)
Nervous system and behavioural effects	Effects on behaviour and habitat use	Birds and mammals	Lai (2014a); Pelletier et al. (2013); Marino et al. (2003); Kramarenko and Tan (2003); Ghosn et al. (2015); Beasond and Semm (2002); Leszczynski et al. (2002); Di Carlo et al. (2002); Salford et al. (2003); Johnson-Liakouris (1998); Gómez-Perretta et al. (2013)	Alter the behaviour and activity	Birds	Withey et al. (2001); Steenhof et al. (2006); Gervais et al. (2006); Chipman et al. (2007); Booms et al. (2011)
Genotoxic effects and potential carcinogenicity	Increase in micronuclei; cell proliferation; decrease survival; increase of mortality by neoplasia; promoters and initiators of cancer	Mammals and humans	Leszczynski et al. (2002); Gandhi and Singh (2005); Balode (1996); Velizarov et al. (1999); Hocking et al. (1996); Michelozzi et al. (1998); Dode et al. (2011); Tillmann et al. (2010); Coureau et al. (2014); Lerchl et al. (2015); Baan et al. (2011); Lai (2014b)	Lower annual survival rates	Birds	Paton et al. (1991); Cotter and Gratto (1995); Withey et al. (2001); Steenhof et al. (2006); Chipman et al. (2007); Gervais et al. (2006); McIntyre (2012)
Fertility, reproduction, offspring viability and sex-ratio	Effects on sperm quality and ovarian development; increase in embryonic mortality and miscarriage rate; biased sex ratio	Mammals and humans	Farrel et al. (1997); Grigoriev (2003); Dasdag et al. (1999); Magras and Xenos (1997); Adams et al. (2014); Weisbrot et al. (2003); Panagopoulos (2012); Tofani et al. (1986); Moorhouse and MacDonald (2005); Vereshchako et al. (2014); Larsen et al. (1991)	Alter reproductive rates; Biased sex ratio	Birds and Mammals	Paton et al. (1991); Pietz et al. (1993); Withey et al. (2001); Tuyttens et al. (2002); Demers et al. (2003); Steenhof et al. (2006); Chipman et al. (2007); Barron et al. (2010); Peniche et al. (2011); Moorhouse and MacDonald (2005)
Navigational disruption	Loss of orientation	Birds and mammals (mice and bats)	Engels et al. (2014); Holland et al. (2008); Malkemper et al. (2015); Deutschlander et al. (2003); Muheim et al. (2006); Phillips et al. (2013)	Changes in movement patterns (could just be a cost of device attachment, and not necessarily RF exposure)	Birds	McIntyre (2012)

in Lyon, France, to assess the carcinogenicity of radiofrequency electromagnetic fields (RF-EMF) including RFs, within the Classification of Carcinogenic Substances in the category of "possibly carcinogenic to humans", Group 2B (Baan et al., 2011). An update of the information and abstracts of research papers published since 2006/2007 on the genetic effects of nonionising EMFs in the RF range report that 74 (65%) genetic studies showed effects and 40 (35%) showed no effects (Lai, 2014b).

5.7. Fertility, reproduction, offspring viability and sex ratio

Oxidative stress and free-radical action might be responsible for the genotoxic effects of RFs, which might affect fertility and reproduction. Several authors have reported a significant increase in the embryonic mortality of chickens exposed to radiation from mobile phones (Farrel et al., 1997; Grigoriev, 2003) and effects on the urogenital system, histological changes and a reduced development of the tubules in the testes of rats have been reported (Dasdag et al., 1999). In a study performed on the influence of a group of radio and television antennae (Magras and Xenos, 1997), a progressive decrease in the rodent birth rate was observed, and the exposed rats became sterile after three or five generations, depending on the levels of radiation to which they were exposed. Pernicious effects on reproduction have also been sufficiently tested in humans (Adams et al., 2014) and insects (Weisbrot et al., 2003; Panagopoulos, 2012).

In pregnant rats exposed to 27.12 MHz RF waves during pregnancy, half of the pregnancies miscarried before the twentieth day of gestation, compared to only a 6% miscarriage rate in unexposed controls and a considerable increase in the percentage of total reabsorptions was found; the time of irradiation plays an important role in inducing specific effects following RFR exposure (Tofani et al., 1986). Some studies have also shown that prolonged exposure to electromagnetic radiation can change the sex ratio in animals (Tofani et al., 1986; Moorhouse and MacDonald, 2005; Vereshchako et al., 2014) and humans (Larsen et al., 1991).

5.8. Navigational disruption

Radiofrequency radiation can cause changes in bird behaviour and navigation (Engels et al., 2014; Balmori, 2015), which can result in a loss of orientation and affect their movement, especially in low visibility conditions. Mammals such as mice and bats use the Earth's magnetic field for orientation (Holland et al., 2008; Malkemper et al., 2015), and this ability can be affected by the influence of weak RF fields

(Malkemper et al., 2015). Laboratory scientists who investigate the orientation of animals are aware of the need to shield the place where experiments are performed to prevent interference with anthropogenic radiation noise, as this can affect the results (Deutschlander et al., 2003; Muheim et al., 2006; Phillips et al., 2013; Malkemper et al., 2015). In the absence of such precautions (filters at frequencies from 0.2 to 200 MHz), the sensitivity to low-level RF fields (at levels found in typical laboratory environments) might be a source of unexplained variability when the spatial behaviour of animals is studied (Phillips et al., 2013). It is paradoxical that, at the same time, field scientists investigating the movements and other aspects of animal biology are providing animals with radio transmitters that emit the same type of radiation, ranging between 27 to 401 MHz according to Mech and Barber (2002), since might be similarly affected in the results concerning their orientation and movement as under laboratory conditions.

Few studies have focused on the effects of RFs on wildlife and ecosystems. About two thirds of the reviewed studies reported ecological effects of RF or EMF (Cucurachi et al., 2013), linking the hazards with different modes of exposure (see Balmori, 2009 & Balmori, 2014 for reviews).

6. Conclusions

Techniques for studying animals to be used in science should not prejudice the welfare or alter the behaviour of the study subjects, nor should the scientific quality of the results be biased (Steenhof et al., 2006). Researchers should incorporate the evaluation of potential effects from research methods into their study design to carefully consider the biases that may exist. The reliability of the data obtained should also be considered to develop methods and equipment that have minimal effects on the study (Cotter and Gratto, 1995; Conway and Garcia, 2005; Barron et al., 2010; Dixon, 2011).

When radiomarking, researchers should assess the relative costs and benefits of obtaining the data to minimise adverse effects on animals (Steenhof et al., 2006; Barron et al., 2010). Many researchers did not have the opportunity to evaluate the effects of radio transmitters because they did not design the experiments accordingly; thus, the absence of evidence should not be interpreted as an absence of effect (Steenhof et al., 2006; Dixon, 2011; McIntyre, 2012). Many of the telemetry studies conducted had no way of using a control group, and no studies have carefully evaluated the long-term effects of radio marking (Dixon, 2011; McIntyre, 2012).

When radio-tracking is used transmitters may affect survival, behaviour or health (Steenhof et al., 2006; O'Mara et al., 2014), and produce biased and incorrect interpretations of the research (Barron et al., 2010). Many aspects of behaviour and ecology were minimally affected, but their cumulative impact could be substantial (Barron et al., 2010), since the effects are long-term (Peniche et al., 2011).

The few studies that have been done to evaluate possible damage and causality only investigated the effects of the weight of the equipment and the type of attachment used (Peniche et al., 2011). The studies that have been done under more controlled conditions (in captive) often have not used radiofrequency radiation and were based on statements or premises of the safety of radiowaves (Small et al., 2005).

Therefore we hypothesise that there is a factor that has not been considered in the findings to date: the electromagnetic radiation (in the RFR band) from radio-tracking devices. Considering this factor may allow researchers to best understand the long-term effects found in Barron et al. (2010), which are similar to those obtained in studies on living organisms exposed to this type of radiation (Table 1). The RFR could explain mortalities found in animals radio marked without a convincing explanation to date (e.g., Peniche et al., 2011). The length of the radio marking will be higher with batteries that are charged by solar panels. In this case, radiofrequency radiation to which the animals are exposed will last longer, and it will be easier also to check for long-term effects as well the intensity of the emission of the most modern equipment is greater.

We believe that this topic is urgent, and propose an experimental approach to study this aspect using radio transmitters emitting radiation with different emission powers, different frequencies and in different experimental periods (also long-term), using a control group. The simulation transmitter studies that have handicapped wild birds with artificial loads of similar size and shape as transmitters could help better inform whether effects are due to the device or the radio signals.

Acknowledgements

The author is grateful to the editor, Pavlos Kassomenos, and the reviewers for their help and advice. The author reports no conflicts of interest.

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