DE GRUYTER Rev Environ Health 2021; aop

Review Article

B. Blake Levitt*, Henry C. Lai and Albert M. Manville II

Effects of non-ionizing electromagnetic fields on flora and fauna, part 1. Rising ambient EMF levels in the environment

https://doi.org/10.1515/reveh-2021-0026
Received February 19, 2021; accepted March 20, 2021;

Abstract: Ambient levels of electromagnetic fields (EMF) have risen sharply in the last 80 years, creating a novel energetic exposure that previously did not exist. Most recent decades have seen exponential increases in nearly all environments, including rural/remote areas and lower atmospheric regions. Because of unique physiologies, some species of flora and fauna are sensitive to exogenous EMF in ways that may surpass human reactivity. There is limited, but comprehensive, baseline data in the U.S. from the 1980s against which to compare significant new surveys from different countries. This now provides broader and more precise data on potential transient and chronic exposures to wildlife and habitats. Biological effects have been seen broadly across all taxa and frequencies at vanishingly low intensities comparable to today's ambient exposures. Broad wildlife effects have been seen on orientation and migration, food finding, reproduction, mating, nest and den building, territorial maintenance and defense, and longevity and survivorship. Cyto- and geno-toxic effects have been observed. The above issues are explored in three consecutive parts: Part 1 questions today's ambient EMF capabilities to adversely affect wildlife, with more urgency regarding 5G technologies. Part 2 explores natural and man-made fields, animal magnetoreception mechanisms, and pertinent studies to all wildlife kingdoms. Part 3 examines current exposure standards, applicable laws, and future directions. It is time to recognize ambient EMF as a novel form of pollution and develop rules at regulatory agencies that designate air as 'habitat' so EMF can be regulated like other pollutants. Wildlife loss is often unseen and undocumented until tipping points are reached. Long-term chronic low-level EMF exposure standards, which do not now exist, should be set accordingly for wildlife, and environmental laws should be strictly enforced.

Keywords: 2G – 4GLTE; 5G; cell phone towers/masts/base stations/small cells; "Internet of Things" (IoT); magnetoreception; millimeter waves (MMW); nonionizing electromagnetic fields (EMF); radiofrequency radiation (RFR); satellites; wildlife.

PART 1: DEFINING THE PROBLEM: TECHNOLOGY AND RISING EMF LEVELS

Introduction: environmental disconnect

Since the advent of electrification in the late 1800s and wireless communications in the 1930s, ambient levels of radiation from devices, broadcast facilities, land-based telecom infrastructure, satellites, and military applications have gradually risen across a range of frequencies in the nonionizing bands of the electromagnetic spectrum. There has been broad discussion in the media and elsewhere about nonionizing electromagnetic fields (EMF) effects to humans, especially since the International Agency for Research on Cancer (IARC) at the World Health Organization (WHO) classified extremely-low frequency (ELF) magnetic fields and radiofrequency radiation (RFR) ([1, 2] respectively) as 2B possible human carcinogens — similar to lead, exhaust fumes, DDT and formaldehyde. But is there a larger environmental downside to rising ambient EMF exposures — particularly RFR — from popular mobile communication devices, WiFi antennas, and all accompanying infrastructure that is being overlooked by

---

***Corresponding author: B. Blake Levitt**, P.O. Box 2014, New Preston, CT 06777, USA, E-mail: blakelevitt2@gmail.com, blakelevit@cs.com
Henry C. Lai, Department of Bioengineering, University of Washington, Seattle, WA, USA, E-mail: hlai@uw.edu
Albert M. Manville II, Advanced Academic Programs, Krieger School of Arts and Sciences, Environmental Sciences and Policy, Johns Hopkins University, Washington DC Campus, USA, E-mail: amanvil1@jhu.edu

environmentalists, researchers, and government regulators alike. We may be missing critical physiological effects across species based on obsolete assumptions about low-level far-field exposures being too weak to adversely affect living tissue. We have yet to take into consideration the unique physiologies of other species, or how they use the environment in ways that humans do not, when we assume that the unfettered use of EMF/RFR can continue unabated and be allowed to grow indefinitely. Ambient electromagnetic fields, such as ELF from powerlines, wiring and electrical appliances, and RFR used in all broadcast, wireless communications, and transmitting devices, are biologically active and may cause adverse effects to different species of living organisms.

Because of the extensive research that applies to this subject, this work is divided into three consecutive parts:

Part 1 explores the research on rising ambient levels of EMFs, how fields are measured, the use of tracking devices in animals, and what new technologies like 5G will add.

Part 2 explores the Earth's natural geomagnetic fields and non-human species mechanisms of magnetoreception, as well as cyto- and genotoxin effects from manmade EMFs. It focuses on the unique physiologies of non-human species, their specific habitats, and how energy travels through different environments. The section then ties what has been seen in the laboratory, as well as field studies, in all frequencies and representative biological taxa at exposures now seen in ambient environments.

Part 3 discusses government exposure standards and explores existing laws already in place in Western countries, then points to how a new vision of aeroecology and electroecology can use those laws to inform policy regarding nonionizing radiation's impacts.

Supplementary materials include extensive Tables of applicable studies per section at extremely low intensity exposures and accompanying references.

There is abundant research on how low-level EMFs affect non-human species, including extensive reviews of nonionizing radiation across all frequencies and environments about which many environmentalists and regulators are unaware [3–14]. In research into the biological effects of EMF, it has been known since the 1960s that many species are sensitive to low-level energy exposures. Numerous laboratory and field studies have noted heightened sensitivity and adverse effects in birds [15–32]; mammals (cows and bats [33–38]); insects [39–54] bacteria/protozoa [55–61]; amphibians [62–67]; fish and turtles [68–82]; and in trees and plants [83–85], among many others.

Living organisms evolved in a matrix of environmental nonionizing electromagnetic fields, particularly the Earth's geomagnetic field. These natural fields are required to keep organisms well and living in harmony. For example, it has long been known that the geomagnetic field is needed to coordinate embryonic development and provide information for directional migration of insects and birds. These fields are relatively weak and also vary with location. For millions of years, living organisms lived and thrived in these fields. It is therefore logical to assume that man-made fields, which are unfamiliar to living organisms, could disturb their normal physiological functions. And this could happen at very low intensities of the unfamiliar fields. The proliferation of wireless communication systems in particular may pose a dangerous challenge to living organisms on Earth. In addition, there is the more difficult challenge that these novel EMF exposures do not allow living organisms to adapt or adjust since technology's signaling characteristics change rapidly as new technologies emerge and are constantly being developed.

Despite accumulating evidence, there has been a broad disconnect in environmental circles regarding the possibility that there may be serious consequences to this increasing cumulative EMF background from devices like cell phones, smart phones/tablets (iPods, iPads, Kindles), wireless Internet (WiFi, 2G, 3G, 4G, 4G LTE, and now the 5G "Internet of Things"), tower/antenna infrastructure needed to support vast wireless services, and the recent 'smart' grid/metering systems being built across industrialized countries by numerous utility companies, as well as the auto industry with anti-collision/remote-sensing devices now embedded in vehicles, among others. In fact, major national organizations like the Natural Resources Defense Council [86] and the Sierra Club [87] are active proponents of smart grid/meters and other wireless technologies in the name of energy conservation without considering EMF's biological effects. When organizations fail to address the growing database of EMF impacts, however, the result is the tacit and/or explicit approval to introduce whole new layers of EMF into every home and neighborhood, without a full examination of what potential consequences may arise. Federal and state regulatory environmental protection agencies in the U.S. are also proponents of smart grid technology [88] with no mention of possible effects to wildlife from EMF.

Reasons for this disconnect include the fact that many biologists are unfamiliar with the research that exists and/or lack the specialized knowledge of bioelectromagnetics needed to assess the published research. There is also an absence of familiarity — and often low comfort levels — with the cross-discipline of bioelectromagnetics, as well as a professional bias against or feelings of intimidation in biologists regarding the 'hard' sciences of physics and engineering which are the natural homes of technology. In fact, other than the embrace of technology to facilitate various research objectives, such as imbedding RFID microchips and/or attaching radio-transmitters to wildlife in order to track migration, behavior, and breeding patterns, biologists can seem incurious about the effects of environmental EMF on living systems. They appear more focused on technology's end point of what it can accomplish rather than how it actually functions as a biologically active entity.

At one time, electromagnetism was understood as integral to the natural world, and still is in many indigenous cultures and throughout Asia. But that knowledge was largely lost in Western cultures during the 20th Century during an era of over-specialization among the sciences, especially between the physics/engineering disciplines, which provide the underpinnings of EMF and energy propagation, and the biological sciences. This has created a chasm in which background levels of EMF continue to rise with each new added technology, yet little research is called for by environmentalists to determine what effects, if any, may be occurring in technology's path in myriad species as well as their habitats.

We are on the cusp of introducing a massive new level of exposures in the extremely high frequency range (EHF 30–300 GHz) never previously used in civilian telecommunications, although it has been used in military radar and some medical applications. This is the new 5G and Internet of Things [89], which uses complex phased millimeter waves that are smaller in wavelength, and therefore capable of reaching resonant match with some insect species [90], as well as disrupting crucial biological functions of numerous other organisms. In theory, this one technology has the ability to disrupt important ecosystems with broad-based effects to food webs. In addition, the top end of these ranges reach infrared frequencies, some of which are actually visible to other species — especially birds — and can impede their ability to sense natural magnetic fields necessary for migration and orientation [91]. Yet no environmental review in the U.S. has been recommended before buildout [89]. Other countries, especially in Europe, are being more cautious.

Historically, the U.S. was the leader in EMF health and environmental research, but now most of that work — and any accompanying public policy recommendations — are coming from Europe and elsewhere [92, 93]. There is virtually no public or private funding in the U.S. for ambient EMF research into the effects on wildlife, despite appeals from federal agencies such as the U.S. Fish & Wildlife Service [94–96] to study the effects of EMF on nonhuman species, and requests to the U.S. EPA and FCC to address exposures to wildlife [94, 96–100]. Industry funded research cannot be considered unbiased. There are no regulations specifically designed to protect wildlife from EMF. All regulations are intended for human health, even as most research has historically been conducted on animal models [94, 95]. The unintended consequences of this, in fact, may be that we know more about EMF effects to nonhuman species than we realize, making a large amount of information available for ecological integration and environmental utilization.

Review studies chosen: defining how low level spatial energy may translate to non-human tissue absorption

Studies on the biological effects of anthropogenic electromagnetic fields number in the thousands (101) and span more than eight decades. However, the majority of the early research studied EMF at intensities much higher than those of man-made EMF in the environment. We raise a fundamental question in this paper: Is low-intensity anthropogenic EMF in the environment capable of affecting physiological functions in living organisms? There is an abundance of studies in very low-level ranges to draw from (see Part 2: Supplements 1, 2, 3 and 4).

The primary focus of this review is on low-intensity far-field EMF exposures, i.e., at some distance for the radiating source, comparable to ambient fields that various species might repeatedly encounter. The studies we reference were chosen according to general significance and specific relevance to the species being discussed in both the text and Supplemental Charts.

There are literally thousands of studies going back to the 1930s (e.g., [90, 102–107]) that used test animals in controlled laboratory conditions to determine EMF effects on humans. To conduct such work directly on humans is ironically considered unethical at the same time we allow technology to flourish. Although most research has been conducted on rodent models such as mice and rats, one unintentional byproduct is that we actually know a considerable amount about how both high and low intensity EMF can affect species such as rabbits, dogs, cats, chickens, pigs, primates, amphibians, fruit flies, bees, Earth worms, various microbes, and yeast cells which have all been used as research models. Typically this work has not been understood as broadly germane to wildlife but in many instances it can be seen as important as illustrated throughout this paper.

The vast majority of the early research prior to the 1960s using animal models was done with high-intensity RFR [108–112] unlike most low-level ambient exposures today. The early work was specifically designed to determine gross thermal effects in humans at a time when electrophysiology and thermoregulatory mechanisms were not well understood. The more subtle non-thermal effects were of little interest then, although certainly known to exist [104–106, 113–115]. Additionally, signaling characteristics were unlike today's complex pulsed digital exposures. Thus the large body of early work is not included in this review except where appropriate for the general understanding of trans-species physiological patterns and for an overall understanding of how energy couples with living tissue which the early work helped delineate.

How government exposure standards relate to wildlife

To develop a sense of the potential relevance of ambient exposures to wildlife, it is necessary to briefly compare standards for human exposure. In the U.S., the Federal Communications Commission (FCC) is the agency authorized by law to regulate the communications industry and grant licenses for radiation transmission/reception/exposure from communications devices. FCC adopted exposure standards [116–118] that include both power density for ambient exposures from transmitting sources (generally defined as the rate of energy transmitted in space) and specific absorption rates (SARs) reflecting the dose rate of energy absorbed in tissue – both potentially relevant metrics to species in the wild.

For power density, the U.S. standards are between 0.2 and 1.0 mW/cm^2 and for SAR between 0.08 and 0.40 W/kg of human tissue. For cell phones, SAR levels require hand-held devices to be at or below 1.6 W/kg averaged over 1.0 g of tissue. For whole body exposures, the limit is 0.08 W/kg. In Canada and throughout most European countries that use the exposure standards created by the International Commission on Non-ionizing Radiation Protection [119, 120], the SAR limit for hand-held devices is 2.0 W/kg averaged over 10 g of tissue. Whole body exposure limits are 0.08 W/kg. At 100–200 ft (30.5–61 m) distances from a cell phone base station (i.e., an antenna or antenna array), a person or animal moving through the area can be exposed to a power density of 0.001 mW/cm^2 (i.e., 1.0 μW/cm^2). The SAR at such a distance can be 0.001 W/kg (i.e., 1.0 mW/kg) for a standing man.

For the purposes of this paper we will therefore define low-intensity exposure to RFR for power density of 1 μW/cm^2 or a SAR of 0.001 W/kg.

Many biological effects have been documented at low intensities comparable to what the population — and therefore wildlife — experience within 200–500 ft (61–152 m) of a cell tower [100]. These can include effects seen in *in vitro* studies of cell cultures and *in vivo* studies of animals after exposures to low-intensity RFR. Reported effects include: genetic, growth, and reproductive alterations; increases in permeability of the blood brain barrier; stress protein increases; behavioral changes; molecular, cellular, and metabolic alterations; and increases in cancer risk (see Ref. [100], Table 1).

Sensitivity to RFR and the setting of exposure standards for humans are mostly based on research data from rats (another mammalian species). In general, however, it is not valid to apply the same data to species more distant on the evolutionary scale, e.g., birds, insects, and trees. Realistically one should only use the available dosimetric data on each particular species to understand its RFR sensitivity, which is why this paper goes into such detail in Part 2 on EMF studies covering all taxa. However, exposure standards set by the FCC and others do not set limits with nonhuman species in mind.

Unlike field research, *in vivo* and *in vitro* laboratory studies are conducted under highly controlled circumstances often with immobilized test animals, typically at near-field, for set durations, at specific frequencies and intensities. Extrapolations from laboratory research to species in the wild are difficult to make regarding uncontrolled far-field exposures, other than for example to seek possible correlations with laboratory-observed DNA, behavioral, or reproductive damage. In the wild, there is more genetic variation and mobility, as well as variables that confound precise data assessment. In addition, there are complex variables like orientation toward the generating source, exposure duration, animal size, species-specific physical characteristics, and genetic variation that also come into play. Assessments for wildlife may vary considerably depending on numerous factors.

It is highly likely that the majority of wildlife species are constantly moving in and out of varying artificial fields. Precise exposure data, however, are difficult to estimate. Nevertheless, there is a growing body of evidence that finds damage to various wildlife species near communication structures, especially where extrapolations to radiation exposure have been made [15, 17, 32, 36, 37, 121–123].

The major question of whether man-made environmental EMF creates biological effects in wildlife species has now become urgent with 5G technologies and potentially more lenient allowances being considered by the major standards-setting committees at FCC and ICNIRP (see Part 3 on government exposure standards and new proposed changes).

Are we using the right physics model in standards setting?

From the beginning, there has been discussion regarding basic physics models used to determine manmade EMF effects to living systems [124–131]. The discussion has focused on classic models of photonic energy vs. wave energy in relationship to thermodynamic equilibrium. These are highly complex biophysics discussions beyond the scope of this paper in anything other than the broadest description. They are included here because of ramifications to the standards-setting models noted above and in Part 3, and particularly regarding effects to DNA discussed in Part 2. These factors are linked and apply to all species.

The electromagnetic spectrum is divided into ionizing and nonionizing bands. Classic quantum theory EMF photon models used to assess ionizing radiation [132] established long ago that ionizing radiation has enough inherent energy to knock electrons off orbits within atoms thereby causing structural cellular changes that are potentially carcinogenic and mutagenic due to DNA damage.

Those same models were then extrapolated to conclude that since nonionizing EMF does not have enough inherent power to displace electrons from atoms, it therefore cannot damage molecules such as DNA directly and certainly not indirectly. Historically, held against that one definition regarding inherent photonic energy, man-made nonionizing EMF has been presumed to be relatively innocuous beyond its ability to heat tissue and cause electrical shock. Most modern technology, including all current exposure standards and categorical exclusions, are based on that rationale, along with observed behavioral effects in animal models. Exposure standards have been strictly based on the easily quantifiable thermal hazards of tissue heating with safety margins built in [116–120]. While those safety margins vary between countries, the fundamental exposure mechanism assumption is not challenged.

What is left out of that narrow model, however, is the fact that all living things are fundamentally coherent electrical systems that interact in highly sensitive ways to minute levels of nonionizing EMF — sometimes at vanishingly low intensities far below current standards [3, 4, 100, 133–135]. This is particularly true of other species that have evolved to sense and use low level EMF fields in surprising ways (see Part 2).

In addition, much of biology is nonlinear. For example, a small amount of bee venom can create an outsized effect (anaphylaxis) in people allergic to bee stings. The weather is also nonlinear [136], e.g., a small perturbation in one part of the world can theoretically result in a major weather event like a tornado in a far distant area [137–139] (This is not to be confused with the so-called Butterfly Effect — or chaos theory of butterfly wing flapping affecting weather events in other parts of the globe, which has never been documented). Evidence has been mounting for decades that biology is more related to quantum states and resonant responses, not to the traditional linear equilibrium thermodynamic models currently used to define what biological effects *should* occur but often do not [127].

Also left out of that narrow linear model, which is based on a single photon acting on a single cell at a singular moment in time, is the fact that today's uses of EMF/RFR involve many photons acting in unison [140] in extremely complex ways such as in phased array technology. In other words, the entire thermodynamic model traditionally used to promote RFR safety regulation may not apply. It also excludes most recent research pointing to both cumulative and synergistic effects [141], and is unable to embody the complexity and totality of today's exposures, much less biological sensitivity in general.

Radiation is not a classical closed system in a thermodynamic equilibrium [142]. Yet it has been repeatedly put forth that devices and infrastructure must be safe because a single microwave photon, for instance, does not have enough energy to break a chemical bond. While that might be accurate for some sources of ionizing radiation, it may not hold true for lower frequency bands that operate within the classical wave limit of high photon densities where the energy of each photon is often irrelevant ([132], updated 2017).

Panagopoulous et al. [143–146] have written extensively on this issue, noting that man-made electromagnetic emissions are very different than what is found naturally in light spectra and the ionizing bands; that man-made EMF is not "quantized." They posit instead that nonionizing EMFs do not consist of photons but rather of continuous waves in high-density photon "packets" described in classical electromagnetism that interact very differently with biological systems than traditional models assume. It remains to be seen if this hypothesis gains wide acceptance.

If we are to truly shift to safer exposure standards, we need an accurate model based on biology, observation, and experimentation, not just physics theory. Typically when contradictory information that goes against popular assumptions reaches a sufficient critical mass, those assumptions eventually give way to more current knowledge. At present, there are no true biologically based standards in existence other than for a narrow range of heating effects. What we appear to have are dosimetry models that easily allow technology to function.

What may be the most accurate model has yet to be determined but may evolve into a new hybrid. It is already well known that distribution of absorbed RF energy in living tissue is not uniform, varying widely within cells and different body areas and organs, which is why SARs are generally averaged [142]. If nonuniformity can be more accurately factored in, subthermal interactions may make sense with or without new mechanistic models being delineated. What has become increasingly clear is that current models no longer withstand close scrutiny in the face of so much contradictory science begging for a more accurate assessment.

Increasing ambient background levels

Exposure to anthropogenic environmental RFR began little more than 100 years ago – an extremely short window from an evolutionary perspective. Amplitude modulation (AM) radio broadcasting was first introduced in the 1920s in the medium-frequency band (500–1,600 kHz), with both frequency modulation (FM) radio and television broadcast in the very-high frequency band (VHF 30–300 MHz) introduced in the 1930s. The end of World War II and advances in technology saw the rapid expansion throughout the 1950s with television stations operating in the ultra-high frequency ranges (UHF 300 MHz–3 GHz; [147]). Throughout the 1970s and 1980s, FM came to dominate commercial radio but AM never stopped broadcasting. From the 1980s through the present, large swaths of high-powered commercial radio infrastructure (50,000,000 W and more) has moved from terrestrial-based towers to satellite platforms, while low-powered FM stations (1,000 W) have increased their terrestrial footprint. There was another exponential increase from the mid-1990s through the present with the introduction of cell phone technology, also in the UHF bands, which has become by far the dominant RFR exposure today [148, 149]. Ambient RFR has since grown into a constant ubiquitous exposure in all industrialized nations from both terrestrial and satellite-based infrastructure.

Today's wireless applications are legion. The latest include smart grid/metering, 3G/4G LTE and now 5G telecommunications networks offering endless click-on "apps," TV/music/video downloads, e-books, photos in the "Cloud", voice, 'smart' homes and personal assistants like Amazon's Alexa, Apple's Siri, and Google Homes, WiFi/WiMax Internet connectivity and texting — all available from a cell phone. Then there are universal GPS systems that work off of satellites and a host of vehicle-mounted radar RFR collision avoidance devices built into vehicles to automatically stop, detect people or animals on the road, or park the vehicle without engaging the driver. Already out of prototype are driverless cars and trucks, as well as a new broadband wireless service that will introduce a new form of ubiquitous WiFi with antennas capable of transmitting in a 12,000 mi^2 (31,080 km^2) radius with a 62 mi (100 km) reach from one antenna. Also rapidly being built in many areas are augmented cell services via distributed antenna systems (DAS) and small cells mounted on utility poles targeted for urban as well as rural mostly RFR-free areas. DAS/small cells will host the 5G Internet of Things (IoT). Then there are new Homeland Security networks like GWEN and FirstNet, and emergency first responder systems like Terrestrial Trunked Radio (TETRA). All of these technologies use extremely complex signaling characteristics carrying a lot of information with potentially complex biological effects. Each new technology introduces a new level of environmental exposure. Just 70 years ago, very little of this existed and its consequences had been little studied or understood until now — a focus of this paper.

With the exception of some developing countries, 2G has largely faded from use in most industrialized nations where third generation (3G) is still operational for global system mobile communications (GSM), while fourth generation (4G) long-term evolution (LTE) has become increasingly popular for smart phones/technology using the universal mobile telecommunications system (UMTS). Gonzalez-Rubio et al. [150] found the highest environmental mean radiation values measured today are for GSM/UMTS/DCS, accounting for approximately 70 percent of outdoor environmental mobile communication exposures, although in some countries, like Turkey, the highest exposure still comes from radio and television broadcasts. First and second generation systems were very frequency specific (850–1,200 MHz) but today there are multi-frequency bands used within systems for up-and download frequencies from devices and base stations — e.g., GSM + UMTS 900 MHz, UMTS 2,100 MHz, LTE 800 MHz, LTE 2,600 MHz and GSM 1,800 MHz bands.

Prior to the telecom buildout in the early 1990s, a detailed sample of ambient baseline data existed based on a 1980 study by the U.S. Environmental Protection Agency

(EPA) which we can compare to today's rising exposures. In the first study of its kind, EPA researchers Tell and Mantiply [151] assessed background levels of broadcast signal field intensity of RFR for three years and obtained data at 486 locations distributed throughout 15 large U.S. cities. The data collectively represented 14,000 measurements of very high frequency (VHF) and ultra high frequency (UHF) radiation (used in television broadcast) in ambient environments with estimated exposure at 47,000 census districts within the metropolitan boundaries of those cities. At the time, ground-based broadcast signals from TV, AM radio and the then-increasing FM radio transmissions were the primary exposures. There were no cellular services, very few wireless devices, and very little satellite transmission compared to today.

The Tell and Mantiply [151] study found that 20 percent of the total U.S. population was exposed to time-averaged VHF and UHF broadcast radiation at a median level (i.e., the middle value of the highest and lowest measured values) of 0.0005 μW per centimeter squared ($\mu W/cm^2$). This represents a measurement of power density in a set space commonly used to delineate RFR field intensity. In Los Angeles, for instance, Tell and Mantiply [151] found the median level was 0.005 $\mu W/cm^2$ [152]. Their data also suggested that only 1% of the population, or about 441,000 people, were potentially exposed to levels greater than 1 $\mu W/cm^2$ — the safety limit recommended by the USSR which was 1,000 times more stringent than the U.S. safety guidelines in 1980. At the time, the researchers clearly found the data reassuring for the general population.

Tell and Kavet [147] revisited the subject in 2014 but specifically did not replicate or try to update the large 1980 study. Their goal was to determine if, and how, environmental levels could now be assessed, given the number and variety of RF transmitters used today. They tested in four small-to-medium size municipalities and found that the FM bands were still a major contributor to overall RFR exposure, but noted that over time, intensities in the VHF bands decreased while the UHF bands increased, reflecting the shift in the UHF bands for cellular use since 1980. European researchers, however, did not find FM to be a significant factor in today's exposures [153–155].

The original 1980 U.S. study cannot be replicated since the profile and nature of RFR has completely changed since that time. But an international team of researchers [149] measured EMF/RFR in 94 matched microenvironments in six countries, including Switzerland, Ethiopia, Nepal, South Africa, Australia and the Los Angeles area of the U.S. — one of the 1980 EPA sites — where they found a 70-fold increase in RF levels compared to the late 1970s measurements [152]. See below for more information on this study with cell phone infrastructure as the dominant contributor. Other than the one Sagar et al. [149] study, there are no current data on background radiation levels in the U.S. However, findings from U.S. and Canadian cities are thought to be comparable to studies coming from Europe which takes more interest in the subject in general as well as quantifying the continuously rising indoor and outdoor levels in particular.

Although cell service did not exist when the original 1980 EPA study was performed, cell technology now functions in similar UHF bands measured by Tell and Mantiply in 1980 [151]. Thus today's rising exposures can be assessed against the baselines noted back then. When the U.S. switched to digital television in 2008, it freed up spectrum "white space" previously used for analog TV transmission. That spectrum space is now allocated for 4G wireless Internet, and both the VHF and UHF bands will be used in expanding ubiquitous broadband/Internet service in rural areas. But the advent of digital technology, which simulates pulsed waves, significantly changed communications signaling characteristics, essentially allowing for a second universal transmission system to be built on top of the old analog signals [100]. This not only doubled overall environmental RFR exposures, it introduced a completely new kind. It was the global introduction of digital technology that facilitated the reshuffling of various RFR bands in the finite "real estate" of the electromagnetic spectrum. The introduction of 5G is now doing the same thing.

There is never enough spectrum to satisfy society's desire for it, a consequence of which is that we have now completely filled in most of the lower nonionizing bands with commercial and military use, and are branching into much higher frequencies using millimeter waves between 30 and 300 GHz for communications and other applications. The U.S. was the first country to approve the buildout of the fifth Generation (5G) communications, to date in the 28, 37, and 39 GHz ranges for 5G. The new 5G systems, using small cells and Distributed Antenna Systems (DAS) networks, are being built with antennas attached to buildings and powerline utility poles in very close proximity to the population, using extremely complex phased array signaling heretofore mostly used by the military. Neither these frequencies nor signaling characteristics existed for civilian use in 1980 and therefore constitute a whole new and novel environmental exposure since that early EPA review, along with all of the other wireless technologies since introduced. One thing is certain — exposure patterns are rapidly changing with each new technology development, far in advance of our biological understanding of the consequences.

With the advent of cell technologies in the mid-to-late 1990s, background ambient RFR exposures began to steadily increase, particularly — though not exclusively — in urban areas [18–149, 156–165]. Cellular infrastructure, though orders of magnitude lower in power density than that from broadcast facilities, has become vastly more ubiquitous and is placed much closer to the human population in both urban and rural areas [155].

Difficulties in assessing ambient exposures

Assessing ambient exposures, both indoors and outdoors, has frustrated researchers and regulators alike regarding how best to capture field exposure data. Should it be through computer simulation or actual field measurements? Variables in environmental assessments can be blindingly complex. Power density and distance from a generating source have traditionally been used as the surrogate for ambient exposures but those metrics can be imperfect given how RFR couples with the environment once transmitted, as well as the necessary factoring in of multiple overlapping sources today. Aside from distance and multiple sources, environmental assessments involve variables such as orientation toward the transmitting source, species, size, physical composition, the presence of metal objects, and topography, to name but a few [100, 155].

RF field strength falls off rapidly with distance from the transmitting source (Maxwell's inverse square law) but predicting actual exposures based on simple distance from antennas using standardized computer formulas is inadequate. Actual exposures are far more complex in both urban and rural environments to both humans and wildlife.

Contributing to the complexity is the fact that the narrow vertical spread of the beam creates a low RF field at ground level directly and at some distance below the antenna. As a person or wildlife species moves away from or within a particular field, exposures create peaks and valleys in field strength. In addition, scattering and attenuation alter field strength in relation to building placement, architectural composition, the presence of trees, soil type, and topographical features such as mountains and rock formations [166]. Power density levels can be 1–100 times lower inside a building, for instance, depending on construction materials used and antenna gain [155]. Exposures can differ greatly depending on the presence of conductive mediums like water or soil containing mineral salts with sodium, iron, copper, and zinc, among others. Exposures can be twice as high in upper floors of buildings as in lower floors [167, 168]. This would also apply to birds/bats/bees and other insects receiving higher exposures when flying at a lateral plane with transmitting antennas mounted on a tower or atop other structures.

Although distance from a transmitting source has been shown to be an unreliable determinant for accurate exposure measurements due to potential creation of RFR hotspots [155], the metric is nevertheless useful in some general ways. For instance, Rinebold [169] has shown that radiation levels from a tower with 15 non-broadcast radio systems will fall off to natural background levels at a distance of approximately 1,500 ft (457 m). This would be in general agreement with the lessening of symptoms in human populations living near cell towers at a distance greater than 1,000 ft (300 m; [170]). There is, of course, no adequate or reasonable way to restrict wildlife from approaching, defending territories, and/or living near towers, including birds nesting directly on or immediately near them.

Animal radiotracking devices: RFID and radio collars

In human populations, wearing or carrying personal dosimetry devices appears to be a promising area for capturing cumulative exposure data. But attaching such devices for the same purposes to wildlife is ill-advised given the amount of tracking equipment — RFID chips, radio collars, and radio/satellite implants — already globally deployed by biologists on/in numerous species of avian, terrestrial, aquatic and marine wildlife for study and media entertainment.

Arguably, important behavior and migratory findings have been discovered for myriad species from such use — including the deep dives of great white sharks (*Carcharodon carcharias)* and the 50,000+ mi (80,470 km) annual "figure eight" migrations of Arctic Terns (*Sterna paradisaea)*, among many others. One of the authors [171] radio-tagged black bears (*Ursus americanus*) in Michigan's Lower Peninsula for three years using receivers on the ground and in aircraft, investigating impacts from humans on bears, but at the time he was unaware of possible impacts from EMF. Aside from the newest telemetry technologies with safety features such as immediate break-away telemeter/collar options, lost collar signaling, and data-card download capabilities, there can still be difficulty removing such devices after attachment/insertion, if at all, or collecting such devices once an animal has died, or devices have slipped off and/or self-released in remote areas.

Most important, however, are data available that confound the additional exposures [172] from the devices themselves, which has not been broadly addressed by the wildlife community. Balmori [8] noted that radio transmitters attached to animals can induce negative effects leading to biased results. Documented effects from use of the devices include decreased productivity, behavioral and movement changes/patterns, increased energy expenditure, biased sex ratios, and reduced survival. Biologists often attribute such factors to the weight of the radio transmitter and/or associated devices. Also the type of attachment (harness, collar, leg clamp, glue, or implant) and where mounted (subcutaneous anchoring, tail, head, wing, etc.) are also considered factors in adverse outcomes. So far, however, EMF/RFR has largely been left out as a confounder, even as adverse effects were found to be significantly associated with the duration of RFR transmitter attachment [8, 173]. This parallels similar effects seen in all wildlife taxa from RFR as demonstrated throughout this paper. Balmori [8] posited that ironically scientists investigating animal orientation understand they must shield their labs to prevent anthropogenic EMF from distorting or skewing research results, yet they directly attach transmitters to species in field studies without considering the confounding exposure of the radio tracking devices themselves on behavior, movement, orientation, and even survival.

Barron et al. [173] published a meta analysis of effects to avian species from use of radio tracking devices. Up until this large analysis, studies were limited to investigations of either the type of device or to a single species. The researchers reviewed 84 studies to determine if devices had an overall effect on avian species, which aspects of behavior and ecology were affected, and importantly, if mere capture and restraint were factors. They found significant overall device-induced negative effects as well as negative effects from eight of 12 specific aspects — most markedly from increased energy expenditure and reduced likelihood to nest. In fact, devices negatively affected every aspect considered except flying ability. Effects were independent of sex, age, primary method of locomotion and body mass. They also found no evidence of greater effects from heavier devices, but breast-mounted and harness attached equipment increased device-induced behaviors such as preening. Device-induced mortality differed between attachment methods with anchored and implanted transmitters (which generally require anesthesia) showing the highest reported device-induced mortality rates. Harnesses and collars also had relatively high mortality rates, possibly due to entanglement with vegetation. They further noted that cumulative impacts from some aspects of attachment were substantial. For example, reductions in nesting propensity, success, productivity, and foraging can all decrease reproductive potential, while reduced foraging, body condition and flying ability, along with increased device-induced behaviors and energetic expenditure, are likely to increase bird mortality with use of transmitters. Also, transmitters on some birds indirectly reduced the fitness of untagged mates if they had to compensate for decreased parental activities by the bird with the transmitter. Capture and restraint however, as independent variables, were not found to be of consequence. The authors deduced negative effects were primarily due to transmitters. They concluded that transmitters and other devices could negatively affect birds and may bias resulting data. Unlike Balmori's 2016 review [8], this study did not specifically include EMF/RFR but it can generally be implied.

Deadly sarcomas have also been observed in tissue around RFID chips imbedded in research animals and domestic pets [174–182] which some attributed to the casing material. Also noted were severe metabolic changes in animals exposed to 915-MHz RFID [183].

Not all animals studied with RFID chips however showed adverse effects [184–187] although most of those tests were of short duration [174]. Very little follow-up data have been collected on possible effects to wildlife after radio collars or other tracking devices have been attached, or what contribution, if any, such devices may be contributing to ambient exposures. Much still remains unknown about the impacts of telemeters in and/or on wildlife.

One field study by Raybuck et al. [188] of Cerulean Warblers (*Setophaga cerulea*), a small long-distance migratory songbird, found a 35% lower return rate when geolocators (also known as dataloggers or geologgers) were attached than in control populations without geolocators. Geolocators are miniature devices with tiny computers that produce a small magnetic field and record light at regular intervals, usually two times per day, enabling general position to be calculated. Birds must be re-captured to gather the range of location information over time. Devices are externally attached to birds with thin straps under their legs or harnesses on their backs and are widely used by biologists to track avian migration over their full annual cycle of spring return, mating, nesting, fledging, fall migration and overwintering. While Raybuck et al. [188] found no negative effects from geolocators during the breeding season, the return rate of geolocator-tagged birds was lower than that of control birds (16 ± 5% vs. 35 ± 7%). They attributed the loss to increased weight from the devices, adverse weather patterns especially to species flying over large bodies of water, return to areas other than expected, and death. The researchers did not explore potential effects from EMF but noted that caution was warranted.

Most wildlife biologists do not factor in the effects of exposures from microcurrents in batteries/computers, RFID chips that do or do not transmit RFR, or GPS radio collars that transmit to satellites which can create independent exposures to wildlife and surrounding environments. Because there is so little information regarding effects of EMF exposure in tagged wildlife, the use of dosimeters carried by humans may provide better information about ambient exposures that may then be extrapolated to wildlife as they move in and out of different habitats. Wildlife should not be equipped with devices to assess ambient EMF, even in remote wilderness areas. Biologists should reconsider the abundant use of such devices as if there are no consequences or confounding of data gathered from them.

Human personal dosimetry devices: capturing ambient field measurements

A novel approach for capturing and quantifying ambient exposures for larger built areas was created by Estenberg and Augustsson [153] for the Swedish Radiation Safety Authority. It involved a car-based measuring system for estimating general public outdoor exposures. The complicated but carefully designed system enabled fast, large-area, isotropic spectral bandwidth measurements covering the frequency range between 30 MHz and 3 GHz. The method allowed the complete mapping of a town with 15,000 inhabitants and a 115 km (71+ mi) reach performed in one day. Areas chosen in Sweden represented typical rural, urban and city areas. The data sets consisted of more than 70,000 measurements performed between 8:00 AM and 6:30 PM local time. Results found median power density was 0.0016 μW/cm2 in rural areas, 0.027 μW/cm^2 in urban areas, and 0.24 μW/cm^2 in city areas. In urban and city areas, mobile phone base stations were the clear dominating sources with GSM and UMTS downlinks. The many factors that affected measurement results were discussed, most crucial being the variation of the actual field strength over time caused by sporadic, pulsed or moving transmitters or by multipath fading due to reflections from moving objects. The authors said "…a single measurement of the field strength from transmitters like the global system for mobile communication (GSM) base stations can be both under- and overestimated depending on whether the burst is caught by the measurement," but added that "the extensive amount of measurements in each data set still ensures that the median or mean power density within a measured district is robust." They also noted that due to the antenna mount on top of the vehicle, both over- and underestimates may also occur between transmitters closer to the ground vs. those placed at a higher level, but added that the repeatability of the measurement method and its ability to locate local hotspots is a positive outcome acquired from using this method. While there are many complexities involved with such mobile measurements, on top of the fact that no standard or existing solution for how such mobile measurements should be carried out yet exists, the approach summarized above nevertheless seems a good start.

Gonzalez-Rubio et al. [150] tried another creative mobile method by placing an EME Spy 140 inside the plastic basket of a bicycle, performing measurements in all 110 administrative (electoral) regions with homogenous population counts in the city of Albecete, Spain. The use of the bicycle allowed better access to all areas of those districts — especially those areas inaccessible with motorized vehicles. The authors specifically sought to correlate exposure levels to known fixed mobile base station sites but surprisingly found they did not correlate. Possible reasons given for the absence of correlation were: orientation of the base station antennas, building construction features, land topography, RFR deflection off of buildings and signal attenuation. Gonzalez-Rubio et al. [150] did not characterize what, if any, contribution to outdoor ambient levels were made by possible leakage from indoor RF transmitters or handheld devices but they did use domestic DECT phones as their control since DECT operates without involving links with outside base stations. Their results averaged three bands of mobile telephone antennas (GSM, Digital Combat Simulator [DCS], and UMTS) in the different regions and found variations of average intensity from 0.04 V/m (0.00042 μW/cm^2) to 0.89 V/m (0.21 μW/cm^2). The study points to the complexities of how RFR dissipates in the environment and that distance from a generating source is an unreliable metric. Calvente et al. [189] earlier found similar wide spatial variability outside of 123 residences in Southern Spain using the same variables, plus seasonal differences. Lahham and Ayyad [190] measured environmental RFR in Palestine using a personal exposure meter EME SPY 140. The total daily exposure from all radiofrequency electromagnetic field sources varied widely among participants depending on their location, the mobile network they use, their activities, and their mode of transportation, ranging from about 0.2 to 0.9 V/m, mainly from WiFi 2G, GSM900 uplink, GSM900 downlink, and FM broadcasting.

Using such mobile measurement approaches in expansive rural areas with road access, as well as fixed measurement sites in very remote locations, would better capture real-time exposures (including intermittent peaks from space-based networks capable of affecting wildlife) than computer simulations or personal dosimeter methods, although dosimeters carried or properly attached to trekking gear could gather pertinent information as well.

Measured levels: (for a table of studies, see Part 1, Supplement 1, "Environmental EMF measurements from around the world")

Prior to the widespread use of the UMTS network in one of the earliest ambient environmental studies after Tell and Mantiply [151], Hamnerius and Uddmar [191] investigated EMF/RF at 16 different sites in Sweden, both indoors and outdoors in city areas like bus stops. The maximum value observed was 0.3 μW/cm^2 and was dominated by GSM 900 MHz. An indoor measurement in an office revealed a value of 0.15 μW/cm^2, 96% of the power density coming from a GSM-900 MHz antenna 328 ft (100 m) away. Measurements in the vicinity of radio and TV transmitters resulted in values up to 0.23 μW/cm^2.

Frei et al. [157] used dosimeters to examine the total exposure levels of RFR in the Swiss urban population. What they found was startling — nearly a third of the test subjects' cumulative exposures were from cell tower base stations. Prior to this study, exposure from base stations was thought to be insignificant due to their low emissions and to affect only those living or working in close proximity to such infrastructure. But this study showed that the general population moves in and out of these particular fields with more regularity than previously expected. That assessment would apply to wildlife, too.

In Frei et al.'s [157] sample of 166 volunteers from Basel, Switzerland, study participants wore a dosimeter for one week and also completed an activity diary. Results found a mean weekly exposure to all RFR and/or EMF sources was 0.013 μW/cm^2. Exposure was mainly from mobile phone base stations (32.0%), mobile phone handsets (29.1%), and domestic digital enhanced cordless telecommunications (DECT) phones (22.7%). Mean values were highest in trains (0.116 μW/cm^2), airports (0.074 μW/cm^2), and tramways or buses (0.036 μW/cm^2) and were higher during the daytime (0.016 μW/cm^2) than the nighttime (0.008 μW/cm^2).

Another surprising finding of the Frei et al. (157) study implied that at the belt, backpack, or in close vicinity to the body in test subjects, the mean base station contribution corresponded to about 7 min of mobile phone use. In other words, ambient exposure from infrastructure alone was a significant contributor beyond one's personal choice to use individual devices. Frei et al. estimated that there had been a 10-fold increase in RFR outdoor radiation since mobile phone technology was introduced than when broadcast RFR had been quantified by Tell and Mantiply [151]. That trend has continued to be measured by numerous researchers today.

Joseph et al. [158] tried to make sense of the measured but differing results coming from various countries. Their objectives were to compare exposure levels and contributions from different sources in different European countries, including Belgium, Switzerland, Slovenia, Hungary, and the Netherlands, standardizing with the same personal dosimeter across countries. Results found that levels were of the same magnitude in all countries except the Netherlands, which was higher in all environments. There was no adequate explanation for these Netherland findings. Highest total exposures, like other studies, were in transport vehicles (trains, cars, buses) due to mobile phone handsets (up to 97%). Exposure in offices was higher than in urban homes. For outdoor urban environments, mobile phone base stations and handsets dominated the exposure.

Others have also looked at various ambient exposures relevant to this paper, including domestic pets and animals sheltering in indoor environments. Viel et al. [165] investigated varying exposures according to day of the week, concluding that the highest exposure to residents was on Sundays, primarily due to UMTS upload transmission and domestic DECT phone use. Markakis and Samaras [159] took indoor measurements with dosimeters in 40 different urban and suburban locations throughout Greece from 2010 to 2012 and found that RF from mobile base stations was dominant in workplaces and schools during the day, whereas in home environments dominant exposures at night were from DECT/wireless phones and computer networks. Bolte and Eikelboom [156] posited that body-worn dosimeters may both under- and -over estimate actual exposures depending on how they are worn and that a calibration determination should be made. They found in their study, using 98 subjects wearing dosimeters, that train stations had a high mean power density of 0.0304–0.0354 μW/cm^2, but that pubs or cafés where more people gathered using mobile phones and laptops in crowded quarters showed even higher exposures with mean exposures of 0.0526 μW/cm^2. That study was conducted in 2011 when GSM use was prevalent, before smart phones using UMTS proliferated. Similarly, Gryz and Karpowicz [192] measured indoor RFR in the Warsaw, Poland, metro. The major source of exposure was the 900 GSM system. Rowley and Joyner [160] found the mean exposure based on 173,323 measurements in 21 countries worldwide was 0.073 µW/cm^2 over a decade. Joyner et al. [193] did further assessments in Africa for seven years and found results consistent with the previous 2012 study. Rowley and Joyner [161] further analyzed a database of more than 50 million data points from the Italian fixed radiofrequency field monitoring network between June 2002 and November 2006 and found the mean value for mobile communications band was 0.047 µW/cm^2. They concluded that the findings of all three studies were consistent irrespective of continent, country, network operator or regulatory RFR exposure limit, leading to confidence that mean environmental levels from cellular mobile communications systems are less than 0.1 µW/cm^2. However, according to Estenberg and Augustsson [153], the methods of these last studies were not well described.

With the introduction of new communications systems and more mobile phone use, measured background levels, not surprisingly, increased. Urbinello et al. [162], who used dosimeters, found a combined 57.1% increase in total RFR levels in European outdoor areas studied within just one year from 2011 to 2012, representing a significantly altered environment over a very short period. They measured three European cities — Basel, Switzerland; Ghent, and Brussels, Belgium — in various microenvironments that included public transportation hubs (train and bus stations), indoor areas (airports, railways, shopping centers), and outdoor areas (residential, downtown and suburb). The highest RFR radiation occurred in public transportation areas which found combined measurement values from 0.32 (272 µW/m^2) to 0.59 V/m (862 µW/m^2). In all outdoor areas combined, values ranged from 0.0128 µW/cm^2 to 0.0446 µW/cm^2. The authors found that the strongest increase in outdoor areas was from communications infrastructure rather than from mobile handsets.

Ambient levels in urban areas can be quite site specific as demonstrated by Hardell et al. [154] when they investigated the Stockholm Central Railway Station, Sweden, using the dosimeter EME Spy 200, which scans 20 different radiofrequency bands from 88 to 5,850 MHz, in order to collect RF exposure data. A total of 1,669 data points were recorded with primary exposures found from downlinks. The median value for total exposure was 0.092 µW/cm^2. The mean total RF radiation level varied between 0.28 and 0.49 µW/cm^2 for each scanning survey (High mean measurements were obtained for GSM + UMTS 900 downlink varying between 0.17 and 0.21 µW/cm^2. High levels were also obtained for UMTS 2100 downlink; 0.044–0.16 µW/cm^2. Also LTE 800 downlink, GSM 1800 downlink, and LTE 2,600 downlink were in the higher range of measurements). Hot spots were also identified, such as close to a wall mounted antenna yielding over 9.55 µW/cm^2 and exceeding the dosimeter's detection limit. It should be noted that these are mostly transient exposures to humans moving through the station, although employees there are subjected to extended exposures as well as any urban wildlife in such environments. This work illustrates the high indoor levels experienced today, perhaps affecting pets, and contributing to rising background levels in general beyond a building's walls. It is also generally indicative of what wildlife would encounter moving near such installations in outdoor areas.

Hardell et al. [155] later investigated outdoor exposures in major areas of Stockholm, Sweden. RF levels were measured during five tours in Stockholm Old Town in April of 2016 using the EME Spy 200 dosimeter with the same 20 predefined frequencies noted above. The results were based on a total of 10,437 samples from which they found the mean total RFR level was 0.4293 µW/cm^2. Similar to their indoor study, the highest mean levels obtained were for GSM + UMTS 900 downlink and long-term evolution (LTE) 2,600 downlink at 0.16 and 0.13 µW/cm^2, respectively. The town squares displayed highest total mean levels, with one example at Järntorget Square measured at 2.4 µW/cm^2 (minimum 0.0257, maximum 17.33 µW/cm^2), compared with results in other areas near the Supreme Court that showed the lowest total exposure with a mean level of 0.0404 µW/cm^2 (minimum 0.002, maximum 0.4088 µW/cm^2). Street measurements surrounding the Royal Castle area were lower than the total for Old Town, with a mean of 0.0756 µW/cm^2 (min 0.00003, max 5.09 µW/cm^2).While their results were below the reference level of 1,000 µW/cm^2 established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), that high-exposure standard, Hardell et al. [155] said, is less credible since it does not take effects into consideration below thermal thresholds for tissue heating and are "…not based on sound scientific evaluation". Their highest measured mean level at Järntorget was 0.24% of the ICNIRP level. Numerous studies have found adverse health effects far below ICNIRP or other such guidelines [100].

The Hardell et al. [155] studies were not compatible with Tell and Kavet [147] that found FM bands were still a significant contributor to ambient RFR exposures. Indeed, Hardell et al. [154, 155] found FM orders of magnitude lower than the most current frequencies used for mobile telecommunications from all sources, the highest contributors were download frequencies from base stations at GSM + UMTS 900, UMTS 2, 100, LTE 800, LTE 2,600 and GSM 1,800 bands.

Similarly, in a study in Switzerland, Sagar et al. [194] reported RFR measurements in 51 different outdoor microenvironments in 20 different municipalities while walking with backpack-mounted exposimeters (ExpoM-RF) through five city centers, five central residential areas, five non-central residential areas, 15 rural residential areas, 15 rural centers, and six industrial areas. They too found infrastructure downlink exposures were most relevant in outdoor areas and that exposures increased with urbanity. They also found uplink exposures from cell handsets were only relevant within public transportation areas (trains, buses, trams), and that repeat measurements were highly reproducible within 2–4 months. Their reported mean RF-MF exposure (sum of 15 main frequency bands between 87.5 and 5875 MHz) was 0.53 V/m in industrial zones; 0.47 V/m in city centers; 0.32 V/m in central residential areas; 0.25 V/m non-central residential areas; 0.23 V/m in rural centers and rural residential areas; 0.69 V/m in trams; 0.46 V/m in trains; and 0.39 V/m in buses. The major exposure in all outdoor locations was from cell phone base stations (480% for all outdoor areas regarding power density).

In the most comprehensive review to date, Sagar et al. [148, 149] measured EMF/RFR in 94 matched microenvironments in six countries, including Switzerland, Ethiopia, Nepal, South Africa, Australia and the Los Angeles area of the U.S. They included both urban and rural areas and matched microenvironments in city centers, central residential, non-central residential, rural centers, rural residential, industrial, and tourist and university areas. This was the first study — ironically initiated by European researchers — to reassess one of the original EPA/Tell and Mantiply (1980) sites in the U.S. where they found a 70-fold (i.e., 7,000%) increase in mean ambient levels since that pioneering 1980 baseline data were recorded [152]. Cell infrastructure was the dominant contributor to the increase. Using portable RFR ExpoM-RF and EME Spy 201, walking with backpack-mounted devices at head height at a distance of 7.8–11.8 in (20–30 cm) from the body, or by driving a car with the devices roof mounted at 5.57–5.9 ft (170–180 cm) above the ground, they measured 94 outdoor microenvironments as well as within 18 public transport vehicles throughout the six countries. Measurements were taken for approximately 30 min while walking and about 15–20 min while driving in each microenvironment, with a sampling rate of once every 4 s (ExpoM-RF) and 5 s (EME Spy 201). They found great variability between countries, and regions within countries, with cell phone infrastructure being the major outdoor contributor to background levels today. Broadcast RFR was second. Total mean RFR exposure in various outdoor microenvironments varied between 0.23 V/m in Swiss non-central residential areas and 1.85 V/m in an Australian university area; and in buses in rural Switzerland between 0.32 and 0.86 V/m in an auto rickshaw in urban areas in Nepal respectively. Uplink RFR connections from mobile phone handsets was generally very small, except in Swiss trains and buses and other transport in sample countries.

Exposure in urban areas tended to be higher. Mean total RFR exposure for city centers was 0.48 V/m in Switzerland, 1.21 V/m in Ethiopia, 0.75 V/m in Nepal, 0.85 V/m in South Africa, 1.46 V/m in Australia and 1.24 V/m in the U. S. Corresponding downlink exposure was 0.47 V/m (Switzerland), 0.94 V/m (Ethiopia) 0.70 V/m (Nepal), 0.81 V/m (South Africa), 0.81 V/m (Australia) and 1.22 V/m (U.S.).

Compared to other countries, the U.S. had high exposure levels, ranging from 1.4 mW/m^2 in a non-central residential area of Los Angeles to 6.8 mW/m^2 in a less populated area within the center of the city near a freeway. The median total exposure to RFR across all eight outdoor microenvironments in Los Angeles was 3.4 mW/m^2. Switzerland, which has stricter exposure standards based on precautionary limits, had the lowest measured levels among all countries in the study.

What the above studies show are steady increasing environmental levels of RFR, primarily due to the introduction of mobile telecommunications. All of the above studies were conducted prior to the introduction of 5G which will greatly increase RFR background levels. The above RFR levels now ubiquitous in the environment are capable of affecting wildlife, as we report in Part 2.

Wilderness areas: cell towers in national parks; military training over the Olympic Peninsula

The studies cited in Part 1, Supplement 1 were conducted primarily in urban and suburban areas with limited attention paid to rural environments. No one has yet measured environmental RFR in heavily forested areas, likely because it is assumed exposures are negligible to nonexistant. Investigators are traditionally more curious about effects in human populations. However, cell towers now transmit into our deepest vast wilderness areas. In addition, sources of environmental RFR include space-based transmissions aimed back toward Earth for military and commercial use, universal satellite transmissions for GPS, airborne transient infrastructure exposures such as Google blimps [195] intended for rural areas, new satellite platforms for 5G Internet connectivity, drone technology, and military blimps used in both war zones and/or for security and surveillance in remote areas [196]. Such blimp "airships" create their own infrastructure by circling large areas or being positioned over a single point on the Earth's surface for both civil and defense applications. They are intended to provide mobile communications specifically in remote areas lacking land-based infrastructure, as well as during disasters when land-based infrastructure becomes dysfunctional. There may actually be more ambient RFR exposure in our remote regions than we have assumed.

In the U.S., the National Aeronautics and Space Administration [197] houses the Socioeconomic Data and Applications Center (SEDAC) and along with the Wildlife Conservation Society, and Center for International Earth Science Information Network (CIESIN 2018, [198]) at Columbia University, published "The Last of the Wild Project, Version 2, 2005 (LWP-2): Global Human Footprint Dataset (Geographic), v2 (1995–2004)." Under this program, which accumulated information between 1995 and 2004, NASA facilitated large global data sets to map the Human Influence Index (HII) regarding impacts on the environment intended for use in wildlife conservation planning, natural resource management, and research on human-environment interactions. In 1 km (0.6 mi) grid cells created from nine global data layers, the HII assessed human population pressure (population density), human land use/infrastructure (built-up areas, nighttime lights, land use/land cover), and human access (coastlines, roads, railroads, navigable rivers). CIESIN 2018 had not considered cell technology or transmission infrastructure as factors in wildlife conservation but it is an important new yardstick for future consideration.

A group of researchers [199] used cell phone coverage as a surrogate measurement for human influence on wildlife. In a case study of the vast Brazilian Atlantic forest, the researchers first demonstrated the correlation between cell phone coverage and the global human wireless footprint, using a database of over 23 million antennas. They then correlated the presence of 45 species of medium to large-size mammals and cell phone coverage for the forest. Researchers recorded 18,211 points of mammalian presence from in-person sightings, animal tracks, and remote camera images. They found wildlife probability of being present under cell phone coverage conditions was on average only 18%, with threatened species correlated far lower at 4%. In other words, species appeared to be avoiding such radiated areas. They further noted: "Most of the species showed a clear negative relationship with cell phone coverage, and threatened species presented an even lower probability, of at least 4% when compared with non-threatened ones. The strong positive relationship between cell phone coverage and the Human Footprint gradient at a global scale corroborated our *a priori* hypothesis that cell phone coverage can act as a surrogate for human presence, even in forested areas were no other footprint evidence is easily detectable." Large cat species, like the Jaguar (*Panthera onca*), and other threatened mammals appeared most affected due to their absence in areas studied. The authors did not take RFR into consideration or individual cell phones in use, only the ability to make a cell phone call.

There are many reasons for wildlife abandonment of such areas, including human presence itself as well as the increased cell infrastructure with accompanying lighting, noise, access roads, and powerline connections creating disturbed/broken habitat since the 2005 Human Footprint Index work noted above. Mining, logging, road building, dams, and other human perturbations can also result in wildlife abandonment. The Macedo et al. study [199] may be a useful new metric for detecting human interference along with what is currently being used in conservation planning and decision making. Factoring the introduction of increased EMF from transmissions, electrical conduit, and new ground currents in pristine areas may create important new exposures that wildlife may sense (see Part 2 for information on magnetoreception), also leading to wildlife abandonment. Areas without cell phone coverage may provide an important new indicator for areas needing enhanced protection before wildlife damage is done [200].

In 2016, Yellowstone National Park, Wyoming, had five towers that provided coverage into some of the remotest regions with additional coverage coming into the Park from towers on all of its vast perimeters [201]. There were proposals for Theodore Roosevelt National Monument, North Dakota, to put a 4G cell tower on the edge of one of the largest stretches of designated wilderness there. Mount Rainier National Park, Washington State, despite opposition, planned to install a 4G cell system at a visitor center that would send RFR deep into the surrounding wilderness [202]. Mount Rainier National Park also reviewed right-of-way permit applications from Verizon Wireless and T-Mobile to install wireless communications facilities within the Jackson Visitor Center in Paradise, an area completely surrounded by wilderness. There was already significant coverage to that federally designated wilderness from surrounding towers on its periphery.

Within a few short years, tower proposals increased exponentially as the U.S government, spurred by industry, made coverage into our remotest regions on federally owned public lands a priority. While many see this as necessary for public safety, others see it as an incursion into our last iconic wild sacred refuges. Grand Teton

National Park, Wyoming, is planning a sprawling network of cell towers within its boundaries to run along its 45 mi (72 km) length from which there may be significant signal penetration [203]. Yosemite National Park has seen six new towers permitted in recent years; Sequoia National Park has a new 138' (42 m) tower; Mt. Rainier has new antennas on a visitor center; Grand Canyon has five new towers proposed along the canyon's rim and Yellowstone is improving infrastructure that would increase capacity by 38 times [203]. The fact that the National Park Service is promoting a sweeping tech build-out of wireless sites — including small cells attached to existing buildings, towers, and enhanced WiFi hubs across many of the 62 national parks — is troubling. Grand Teton alone is slated for nine new tower sites in addition to two existing ones, as well as 60 mi (100 km) of new fiberoptic cable as backhaul. Glacier National Park, Montana, is planning at least four new towers; new towers are also planned at Olympic and Bryce Canyon, and Glen Canyon National Recreation Area. At Yellowstone, cell phone users can reportedly already get weak signals across significant portions of the 3,500-square-mile (9,065 km^2) Park's backcountry [204].

While some of the early tower applications got minimal environmental review, the most recent build-outs have evaded regulatory oversight due to the National Park Service declaring specific proposals as categorically excluded, thus negating full National Environmental Policy Act (NEPA) review and implementation of an Environmental Impact Statement/EIS [204]. All of this was made easier by new FCC rules that limited local control, environmental review, and compliance with the National Historic Preservation Act. That FCC ruling has since been successfully challenged in Federal court by the Natural Resources Defense Council [205]. Potential effects to forest wildlife from RFR have not been included but should be part of all applications under NEPA review (see Part 3).

It is well known that signal propagation loss can be due to several factors, including antenna height, depolarization, humidity/rain, tree species, and other variables [206]. Any attempt to intentionally direct strong RFR signals into remote forested areas from ground-based transmitters is confounded by tree leaves that absorb, defract, and scatter signals in myriad directions due primarily to moisture content. Live trees with wet leaves absorb RFR most efficiently while dead trees without leaves absorb the least [207]. Some evergreen tree species also have resonant properties due to needle configurations.

5G is of particular concern regarding vegetation, especially if satellite-based. The technicalities of propagation loss in forest environments are therefore getting renewed attention since rural areas are targeted 5G-service regions for satellite use. The subject is also of interest in the development of wireless sensor networks using low-power transceivers in remote regions for scientific and surveillance purposes [206]. As far back as 1997, the U.S. Federal Communications Commission issued a report [208] on millimeter wave (MMW) propagation characteristics that included information on signal loss due to foliage. In the frequency range between 200 MHz–95 GHz, the foliage signal loss at 40 GHz at a penetration of 32.9 ft (10 m) — equivalent to one large tree or two in tandem — was determined to be about 19 dBm (a unit of measurement of EMF-RFR power levels expressed in decibels referenced to 1 mW). The report noted this is not a negligible signal loss value. The report also discussed signal attenuation effects due to rain, as well as water vapor absorption and oxygen, noting resonant frequencies below 100 GHz occur at 24 GHz for water vapor and at 60 GHz for oxygen. Hakusui [209] also investigated 60 GHz and O_2 absorption properties, as have others. There may be implications for climate change (see Part 3).

Clearer dosemitry standardization is being called for regarding 5G buildout in general, including in urban areas as trees can also affect 5G network designs there too. Government entities are now issuing reports on performance impacts to 5G networks from physical features not previously considered in network planning, including vegetation. The accumulation of new propagation data is now considered an essential prerequisite to 5G's use of higher frequencies [210].

Unfortunately, such reviews are conducted as a component of cost-effective 5G buildout which will use the broadband spectrum spanning low-MHz-through-MMW, not as a tool to mitigate damage to flora which can be considerable. Ultimately the 'greening' of cities to offset impacts of climate change may prove incompatible with 5G. And there is no way to know at this point what 5G exposures from satellites may do to deep forested areas or to climate conditions given resonant factors involving water and oxygen molecules.

Military training over the Olympic National Forest and Olympic National Marine Sanctuary: a case study

One of the more dramatic intentional RFR incursions into pristine government protected forest lands was proposed in 2012 by the U.S. Department of the Navy's Northwest Training & Testing program [211–213] to practice electronic war-gaming exercises in airspace over the Olympic National Park (a UNESCO World Heritage Site), Olympic

National Forest, and Olympic National Marine Sanctuary — all in or off Washington State. The Marine Sanctuary is the preferred key habitat for 29 species of marine mammals, including migrating gray whales. The National Park and National Forest are key habitats for two migratory bird species listed on the Endangered Species List — the Marbled Murrelet (*Brachyramphus marmoratus*), a diving seabird that nests in old growth forests, and the Northern Spotted Owl (*Strix occidentalis caurina*), which thrives only in quiet intact old-growth forest habitats. In fact, the entire Pacific Coast is on the critical Pacific flyway for migratory birds with an estimated one billion birds migrating along the pathway annually [214]. The Olympic National Park is widely seen as among the most beautiful wilderness areas on Earth where temperate rainforest lowlands are topped by majestic glacier peaks. Once designated the "quietest place" in America by the acoustic ecologist Gordon Hempton from the One Square Inch project [215–217], it is home to several plant and animal species that exist nowhere else on Earth.

The massive Navy project includes training over land, air, and sea as well as underwater, including offshore areas of northern California, Oregon, and Washington, the inland waters of Puget Sound, the San Juan Islands, many portions of the Olympic Peninsula, parts of Canada, and Western Behm Canal in southeast Alaska [218, 219]. The Navy has been conducting similar exercises — though nothing like the magnitude of the current upgrade — in this area for decades because it includes the complex environments that service personnel may encounter [220].

After significant community comment and a lengthy environmental review by experts opposing the proposal, the Navy released its Draft Supplemental Environmental Impact Statement (DEIS) calling for increased training and flights over Olympic National Park [221]. Potential adverse EMF effects from the upgraded exercises should not be underestimated. Manipulation of the electromagnetic spectrum has become a pre-eminent offensive and defensive war feature waged on land, in the air, and on/under the world's oceans. The Navy's exercises, conducted under the Northwest Training and Testing [222] program, has not given information (for stated security reasons) on all signaling characteristics, but for the overland activity they will be using frequencies between 4 and 8 GHz at a power output of 90–300 W, 45 min per hour, at thermal and nonthermal intensities, according to personal communications between the Navy and the U.S. Fish and Wildlife Service [223, 224].

While the Navy has operated the Naval Air Station on nearby Whidbey Island since World War II, the proposed upgrades could in time add up to 160 new "Growler" EA-18G supersonic jet warplanes — the loudest aircraft in the sky — to the Northwest Electromagnetic Radiation Warfare program [221, 222, 225]. Training exercises can fly as low as 1,200 feet (366 m) above sea/ground level (AGL) — well within the height of migratory and daily bird-flight movements of numerous avian species ranging from waterfowl, shorebirds, raptors, songbirds and more [226]. In studies conducted by USDA/APHIS Wildlife Services on movements of Osprey (*Pandion haldiaetus*) around Langley Air Force Base, Hampton, VA, Osprey frequently reached these altitudes on feeding and territorial forays and migrated at flight heights averaging 1,300 ft (396 m) AGL at speeds of around 35 mph (56 kph) [227].

On land, the exercises include mobile trucks carrying RFR emitters mounted 14 feet high along remote dirt roads that can reach elevated peaks/ridgelines deep within the forest to communicate with warplanes. There are also new fixed cell towers. There are 2,900 allowed exercises over wilderness and some communities, 260 days a year, lasting 8–16 h per day. There are additional training exercises over/under the water using sonar and lasers capable of causing adverse effects to fish and marine animals [228]; also see Part 2 for potential effects to aquatic mammals, fish, and turtles).

Growlers are equipped with extreme high intensity, multi-frequency detectors and radar jamming technology capable of thermal and non-thermal effects to humans and wildlife alike. One exposure estimate during exercises noted that spending more than 15 min in designated areas could result in thermal damage [213]. Mid-air two-way training involves RFR directionally aimed from plane-to-plane, ground-to-air, and air-to-ground. Despite environmental reviews which were limited in scope there is no clear understanding of what this may do to the environment [228].

After a long review process required by the National Environmental Policy Act [229], the Navy released a final Environmental Impact Statement (EIS) and an Overseas Environmental Impact Statement (OEIS) [230] but the final findings, which remained the same as in earlier drafts, had been widely criticized as inadequate for its broad findings of "no harm," grossly under-estimating present and proposed activities, improperly segmenting activities to minimize scrutiny of collective substantial impacts in violation of NEPA which does not allow such segmentation, and ignoring potential noise effects [225, 231–233]. In March 2017, the U.S. EPA requested more information on potential noise effects but mentioned nothing about EMF effects to wildlife or humans. The Navy's DEIS minimally addressed EMF but repeatedly adhered to parsed language from the Endangered Species Act, noting that electromagnetic devices used during training may affect — but are *not likely to adversely affect* — the various species reviewed, primarily marine animals and some birds. Their conclusions remained the same in 2020 [234].

The U.S. Fish and Wildlife Service (FWS) concurrence [235, 236] was despite former agency career scientists requesting more caution [212]. Extensive attention was paid to the endangered Marbled Murrelet known to nest there, and the Northern Spotted Owl which was said to be shielded from EMF exposures under the forest canopy. Forest canopies, however, are easily penetrated by RFR even though trees are efficient attenuators [237, 238]. U.S. FWS noted that clear line-of sight transmission would limit wildlife exposures; that only birds in flight over the tree canopy could be affected. They found Marbled Murrelets could be intermittently exposed to RFR during flight but that Spotted Owls under forest canopies are not. They then concluded that the effects of brief, intermittent exposures to 4–8 GHz would likely be insignificant to in-flight birds. They discounted physical effects from tissue heating and/or burns [235].

By most measures, the Navy and U.S. FWS conducted poor reviews [233]. Although they did include several bird/wildlife studies [9, 15, 20, 22, 95, 239, 240], they dismissed them for various reasons. Only Bruderer et al. [241], at approximately 9 GHz exposure, was deemed applicable but it found no effects to birds' flight patterns in the presence of radar. Other uninvestigated research that could have applied included in-field RFR behavioral studies [17, 242]; mortality [134, 243, 244]; reproductive outcomes [16, 18]; and bat insect foraging [36] in the presence of radar. Presence of exogenous RFR could also disturb the sensitive magnetoreception of many species, affecting bird and insect migration patterns.

There continues to be no monitoring for EMF/wildlife effects over the wide on-land/over-sea training areas, despite the fact that the final Navy EIS/OEIS noted sources of in-air electromagnetic exposures from a single ship would operate continuously across a wide range of frequencies from 2 MHz to 14,500 MHz, with maximum average power between 0.25 and 1,280,00 W [234]. A publication from one of the authors of this paper [96] was used to justify program approval based on birds‘ natural avoidance behaviors when physical discomfort is caused, such as thermal heating. The Navy and U.S. FWS conclusions that no long-term or population-level impacts to birds will occur may not be supportable.

Although the military is by law allowed use of public lands for training, this deep incursion into pristine protected public lands in Washington State sets a bad precedent. The Navy's project is possibly in violation of federal statutes including U.S. Code 475 (LII, 2018), which outlines the purposes for which national forests were established and how they are to be administered. The U.S. Forest Service, nevertheless, granted the Navy a preliminary Special Use Permit. The National Parks Conservation Association (NPCA) had submitted a Freedom of Information Act (FOIA) request in 2016 to the Navy regarding Growler noise and environmental disruption. After the Navy repeatedly withheld critical FOIA information on the aircraft overflight training, NPCA sued the Navy in mid-2019 for that information's release. As of this writing, no federal court decision has been reached on the FOIA lawsuit.

In 2020, after the upgraded training exercises commenced, noise levels from the flyovers were found by Kuehne et al. [245] at 110 ± 4 dB re 20 μ Pa rms and 107 ± 5 dB A, to exceed known thresholds of behavioral and physiological impacts for humans, as well as terrestrial birds and mammals. Even underwater sound levels from the aircraft, at 134 ± 3 dB re 1 μ Pa rms, exceeded thresholds known to trigger behavioral changes in fish, seabirds, and marine mammals, including endangered southern resident killer whales (*Orcinus orca*). Although soundwaves are not strictly considered EMF, their inclusion here illustrates adverse anthropogenic effects due to inadequate regulatory oversight.

The Navy has been allowed to introduce the loudest aircraft in the sky into one of the quietest places in the U.S. with accompanying complex close-range EMF. With the exception of this high-intensity RFR training program in Washington State, most of the studies cited throughout these consecutive papers found ambient exposures were below any international guidelines for humans but well within the range seen to affect flora and fauna.

New technologies: 5G and the internet of things (IoT)

We are on the cusp of introducing a dense and expansive new layer of RFR into the global built-environment and throughout rural regions using Extremely High Frequency (EHF) millimeter waves (MMWs) between 30–300 GHz for Fifth Generation (5G) telecommunications. On the electromagnetic spectrum, this band lies between the super-high-frequency (microwave) bands and optical (infrared) bands.

5G is a wireless network of machine-to-machine communications called the Internet of Things (IoT) that will allow remote communications between a host of devices and appliances, such as between cell phones and refrigerators, lights, furnaces, entertainment units, security systems for homes and businesses, medical appliances, driverless cars, and every imaginable and "… yet-to-be imagined …" thing [89]. Some of these applications are already available over 4G LTE for 'smart' home environments that consumers can remotely control via their own WiFi systems. Others are programmable, like thermostats, and require no real-time human interaction beyond setup. Since any one of these wireless portals opens access to all others, including computer systems as well as wireless phones, security is a serious concern. Numerous incidences of hacking through smart domestic appliances like refrigerators and baby monitors have already been reported [246]. While the above description is for 5G consumer applications, 5G is primarily for business data accumulation and uses like Internet/consumer tracking.

Because 5G functions in much higher frequencies with shorter wavelengths than previous iterations of wireless communications, a vast new layer of infrastructure requiring millions of new antennas placed very close together — by some estimates every 2–5 houses apart — will be needed to provide ubiquitous coverage. The reason for this densification is because MMWs are easily attenuated and diffracted by buildings, trees, other vegetation, topography and weather conditions (including rain), as well as the shift to higher frequencies because there is little room left in the ultra high frequency (UHF) microwave bands currently used for telecommunications between 800 MHz and 2,250 GHz. 5G networks work mostly off taller cell towers (macro cells) via Distributed Antenna Systems (DAS) and/or small cell antennas (micro cells) attached to buildings, powerline utility poles and municipal lampposts in very close proximity to the human population. Fiberoptic cable provides the backhaul between antennas. Environmentally safer 100% wired fiber-to-the premises networks and 5G wireless applications can no longer be kept separate. Where fiber networks exist, wireless small cells will piggyback onto them [247, 248]. At 28–95+ GHz, that frequency range is significantly higher than the 2.45 GHz used in today's telecom or in products like microwave ovens. In fact true 5G is designed to be an ultrawide-broadband network that can encompass a wide swath of frequencies between the low MHz range and eventually 95+ GHz. In addition, there are general categorizations for low (<1 GHz), mid (between 1 and 6 GHz), and high (>24 GHz) bands that may be used in various iterations of 4G LTE and eventually 5G [247].

The U.S. was among the first countries to approve the buildout of 5G with licensing auctions in the 24, 28, 37, 39, and 47 GHz ranges thus far with higher bands extending above 95 GHz allocated for future use [89, 249, 250]. As of this writing, there has been limited buildout of true 5G networks — some systems advertised as 5G are really enhanced 4G LTE — in select U.S. cities and on military reservations [251]. Other countries have leapt ahead with 5G, including China, South Korea, the United Kingdom, Italy, Spain, Germany, Ireland, Australia, and The United Arab Emirates [252]. But overall, broad 5G buildout has been somewhat slow in coming for technical, financial, human health, and societal reasons. Some countries in Europe, as well as Canada and Russia, are being cautious [92, 93, 253]. There has also been large-scale consumer resistance in many countries and numerous petitions by professionals calling for a slowdown until more is known about the impacts of 5G [254]. Space-based 5G networks are also being built, beaming MMWs back toward Earth from thousands of new mid-and-low Earth orbiting satellites.

All of this development has been done with virtually no environmental consideration or review [89, 249]. Beginning in 2017, the U.S. Congress passed several 5G-enabling bills but significant local and state resistance arose to what is widely seen as a giveaway of public utility corridors (where most ground-based 5G antennas will be mounted) to private enterprise without adequate compensation or local zoning review [255]. Nevertheless, industry pressure has successfully influenced U.S. legislators and the FCC to bypass local review for environmental and historical significance regarding infrastructure siting. No environmental review in the U.S. was recommended before buildout [89]. Indeed, the FCC streamlined local and state review for environmental effects and historic significance against overriding federal legislation requiring such reviews under the National Environmental Protection Act (NEPA) and the National Historic Preservation Act (NHPA). But the Natural Resources Defense Council challenged that ruling in court and won [205], thus preserving NEPA for now (for more, see Part 3).

Military use of millimeter waves

Millimeter waves have been used by the U.S. military since the early 1980s [256, 257]. Millimeter waves are so-called because the wavelengths are smaller (about 1/8th inch or 3.2–5 mm long) than microwaves used in cell phone/WiFi technology at 2.4 GHz (6.3 inch or 12.5 cm). The smaller the wavelength, the higher the energy density per wavelength unit. In this case, with MMW it is about 25 times higher than with cell technology microwaves [258]. This means MMW are capable of resulting in significant damage throughout the biome, including possibly to all flora and fauna present, but not due to wavelength alone. The multiple biological effects from intense energy absorption at very small wavelengths, e.g., in human skin cells or any thin-skinned species, and especially in insects which lack efficient heat dissipation, may cause intense heating with concomitant cellular destruction and organism death. Many of these effects are independent of power density, and therefore not covered by current regulations which are power-density and/or SAR-based. There is, however, a provision in the new ICNIRP standards that makes MMW and 5G subject to dosimetry measurements in power density in the higher frequencies, not SAR (see Part 3).

Millimeter waves have never been used before for civilian telecommunications although the U.S. military has used MMWs at 95 GHz for crowd control and perimeter defense in a skin-heating directed-energy technology called "Active Denial" as part of the U.S. Non-Lethal Weapons Program [259]. The military deployed MMW technology in 2006 in Afghanistan and in the second Iraq war with an Active Denial weapon mounted on Humvees. Named Project Sheriff, it is a Raytheon-designed device in their Silent Guardian Protection System. Biological effects have been researched for decades at the Directed Energy Bioeffects Division, Human Effectiveness Directorate, Air Force Research Laboratory at Brooks Air Force Base in San Antonio, TX [260], as well as other military laboratories and programs like the Defense Advanced Research Projects Agency [261]. Unfortunately, most of this tax-payer-funded research is classified even as there is a critical public need-to-know with the 5G buildout, the proliferation of media misinformation, and burgeoning conspiracy theories. Other countries, like Russia and China, have adopted directed energy technologies too.

Active Denial weaponry was originally developed by the military for large roof-mounts on military vehicles but much smaller mobile units have now been deployed in moving aircraft and ground vehicles. Raytheon has developed a smaller version of Silent Guardian for use by non-military law enforcement agencies and other security providers. That system is operated with a joystick plus an aiming screen that can target people over 820 ft (250 m) away. One Los Angeles county jail has installed a unit on their ceiling. Such systems base their response on an intolerable heating sensation in the skin with the accompanying instinctive avoidance behavior. The sensation supposedly stops quickly when the beam is turned off or a person moves out of range. However, several reports note that numbing sensations can last for hours and blistering has occurred [262].

The U.S. military continues to develop its non-lethal weapons program, announcing in 2019 a $30.8 million (U.S. dollars) contract to General Dynamics for research on directed energy systems, bio-mechanisms, human effectiveness analysis, and integration under the U.S. Air Force's Directed Energy Bio-effects Research (DEBR) program. The aim is to quantify the effects of directed energy weapons using optical, RFR, and MMW radiation, as well as electromagnetic propagation characteristics [263]. It remains to be seen if this information will be declassified or if any will be applied to impacts on wildlife.

Russia has taken a different approach using lower frequencies for 5G, and set up monitors in Moscow to measure/study 2G through 5G effects on citizens under The Izmerov Research Institute of Occupational Health. The Institute will send results to the Ministry of Health and the Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing for the final determination regarding human safety standards [264]. There are no similar epidemiology studies being conducted in the U.S. and it remains to be seen if Russia will release their findings or even the parameters of their research.

Adaptations for civilian telecommunications for 5G in frequencies lower than 95 GHz are theoretically below thermal power intensities [111, 265]. However that does not mean serious concerns are unfounded. Recent updates to the ICNIRP standards propose allowances that will permit exposures to exceed thermal thresholds under certain circumstances (see Part 3). This is a region of the electromagnetic spectrum that has had little attention from the civilian professional groups that set exposure standards, partly because few consumer devices have operated in this frequency range before and devices already using MMW have traditionally had little applicability to high levels of human exposure [111, 265]. All of this is about to change. The new 5G networks also use extremely complex signaling characteristics that are not well studied or understood, including beam steering, massive MIMO (multiple-input, multiple-output) and phased array that have unique biologically active properties.

Some assume minimal and/or reversible risk in humans due to MMW shallow energy penetration, short wavelength, and induced quick fleeing behavior. Damage to wildlife is considered collateral, if considered at all.

Millimeter waves and biological effects

It has been known for over 100 years that MMW are highly biologically active [266–268]. As noted in Pakhomov et al. [269], coherent oscillations in this frequency range are virtually absent in the natural electromagnetic environment, indicating important potential consequences since living organisms could not have developed adaptive mechanisms to MMW during evolution and development, unlike in other areas of the electromagnetic spectrum. In addition, Golant [270, 271] and Betzkii [272] noted that some specific features of MMW radiation, plus the absence of background MMW external "noise," may indicate this band is important for communication within and between living cells. In other words, there may be a reason for the absence of MMWs in the background environment, and more importantly, because of that absence, living cells may have developed their own dedicated uses in that area of electromagnetic spectrum.

Betskii et al. [273] also pointed out that MMW radiation is virtually absent from the natural environment due to strong absorption by the atmosphere and the fact that MMW waves are readily absorbed by water vapor. The authors elaborated on the hypothesis that low-intensity MMW may have broad nonspecific effects on biological structures/organisms and that vital cell functions may be governed by coherent electromagnetic EHF waves. Their results included alternating EHF/MMWs used for interaction between adjacent cells, thereby interrelating/controlling intercellular processes in the entire organism. The above authors [269–273] noted that while these ideas are theoretical, they may plausibly explain the high MMW sensitivity observed in biological subjects.

Chronic long-term, low-level ambient exposures to MMWs are yet to be studied but some extrapolations can be made based on the extensive database that does exist. These higher frequencies may also have unique biological effects to nonhuman species due to size differences, distinctive physiological characteristics, and diverse habitats. Both aqueous environments and the high water content in living organisms may make MMW exposures particularly unique due to the way MMWs propagate though water with virtually no impedance [274–279]. Also, unlike RFR at lower frequencies, in the EHF/MMW range a small power density can lead to a very high local SAR due to the concentration of energy in a small volume in an exposed organism. Heating may be inevitable [280].

Millimeter wave energy, with the very small wavelengths associated with such high-frequency radiation, couples maximally with human skin tissue. Because of this efficient skin coupling, beneficial/therapeutic effects have been known for decades, especially in former Soviet Union countries, from short-term MMW exposures, while longer exposures have produced potentially adverse effects [258, 269, 281, 282].

In humans, Gandhi and Riazi [257] estimated that 90–95% of incident energy of MMWs can be absorbed in human skin with dry clothing, with or without an air gap. Because of sub-millimeter depths of penetration in skin tissue, superficial SARs as high as 65–357 W/kg are possible. Eyes are of particular concern. MMW frequencies penetrate less than 1/64 of an inch (0.4 mm) — about the thickness of three sheets of paper. Except for adult human eyelids and exposure to infants, MMWs supposedly avoid the skin's second dermal layer [265].

However, skin tissue contains critical structures like blood and lymphatic vessels, nerve endings, collagen, elastin fibers, and hair follicles, as well as sweat, sebaceous and apocrine glands. MMW effects to skin have been found to be considerable in glandular tissue with multiple cascading effects throughout the human body even without deep penetration [283]. Effects to lipid cells decreased cell membrane water permeability, with partial dehydration of the cell membrane, and cell membrane thickening/rigidity was seen at 52–72 GHz at incident power densities of 0.0035–0.010 mW/cm^2 [284]. Human sweat ducts in particular may act as coiled helical antennas and propagate MMW energy as a waveguide at these higher frequency exposures causing uniquely higher specific absorption rates [285] not reflected in today's standards. A significant new look at the 5G standards is clearly called for.

Betskii et al. [273] noted that with MMW exposure, skin presented five mechanistic entry points capable of affecting an entire organism. For example, they noted that because MMWs penetrate human skin to a depth of 300–500 μm and are almost completely absorbed in the epidermis and the top dermis, MMWs are therefore capable of directly influencing central nervous system receptors. These include mechanoreceptors, nociceptors, and free nerve endings; APUD cells such as diffuse neuroendocrine cells, mastocytes, and Merkel cells; and immune cells such as T-lymphocytes. In addition, they noted that MMWs produce direct effects on the microcapillaries and other biologically active cells. These five "entry gates" can determine both therapeutic and/or adverse effects as a novel trigger to basic regulatory systems, involving the complete organism. Depending on the parameters of the MMW stimulus and the functional state of the subject exposed, effects produced can be both nonspecific and specific.

In their review, Betskii and Lebedeva [286] also discussed MMW effects on human and non-human models as dependent on exposure sites and noted such effects were highly frequency sensitive. They also described the complex hypothetical mechanism that stochastic resonance (see Part 2) may play in very sensitive water-containing biological species to very-low intensity EMF (in µm ranges) based on the generation of intrinsic resonance frequencies by water clusters that fall between about 50 and 70 GHz. When biological species are exposed to extremely weak EMF at these frequencies, their water-molecule oscillators lock on to the external signal frequency and amplify the signal by means of synchronized oscillation or regenerative amplification. Since MMWs pass through aqueous media almost without loss but also with high absorption, in the process they are capable of deep penetration involving internal tissue and organ structures. The researchers summarized what is known about effects of MMWs. These included a long list of findings in human and non-human models, e.g., EHF's strong absorption by water and aqueous solutions of organic and inorganic substances; affects to the immune system; changes in microbial metabolism; stimulation of ATP (adenosine 5′-triphosphate) synthesis in green-leaf cells; increases in crop capacity (e.g., pre-sowing-seed treatment); changes in certain properties of blood capillaries; stimulation of central nervous system receptors; and the induction of bioelectric responses in the cerebral cortex. Biological effects depend on exposure site, power flux density and wavelength in very specific ways. In addition, low-intensity MMWs were detected by 80% of healthy people, but perception was asymmetrical. Peripheral applications were found to affect the spatiotemporal organization of brain biopotentials, resulting in cerebral cortex nonspecific activation reactions. MMW-induced effects are perceived primarily by the somatosensory system with links to almost all regions of the brain. The authors also discussed water and aqueous environments' unique role on MMW effects, which induce convective motion in the bulk and thin fluid layers and may create compound convective motion in intra- and intercellular fluid. This can result in transmembrane mass transfer and charge transport can become more active. EHF can also increase protein molecule hydration.

In wildlife, especially small thin-membrane amphibians like frogs and salamanders, even at penetration less than 1/64 of an inch (0.4 mm), deep body penetration would result. Effects to wildlife could be significant. In some insect species that would equal deadly whole body resonance exposure [90]. In a recent study, Thielens et al. [287], modeled three insect populations and found that a shift of just 10% of the incident power density to frequencies above 6 GHz would lead to an increase in absorbed power between 3 and 370% in some bee species, possibly leading to behavior, physiology, and morphology changes over time, ultimately affecting their survival. Insects smaller than 1 cm showed peak absorption at frequencies above 6 GHz. In a follow-up study of RFR, Thielens et al. [288] used *in-situ* exposure measurements near 10 bee hives in Belgium and numerical simulations in honey bee (*Apis mellifera*) models exposed to plane waves at frequencies from 0.6–120 GHz – frequencies carved out for 5G. They concluded that with an assumed 10% incident power density shift to frequencies higher than 3 GHz, this would lead to an RFR absorption increase in honey bees between 390 and 570% — resulting in possible catastrophic consequences for bee survival.

In birds, hollow feathers have piezoelectric properties that would allow MMWs to penetrate deep within the avian body cavity [26, 27]. 5G's complex phased MMWs may also be capable of disrupting crucial biological function in other species. In theory this one technology has the ability to disrupt critical ecosystems and the living organisms within them with broad effects throughout their entire food webs. In addition, the top end of these ranges reach infrared (IR) frequencies, some of which are actually visible to other species, especially birds, and could impede their ability to sense natural magnetic fields necessary for migration [91] as well as other crucial aspects of avian life.

There were several early reviews of MMW studies beginning in the 1980s that examined subjects like theoretical modeling and possible interaction mechanisms [289–293]. Pakhomov et al. [269] also published an extensive review of MMW research, examining over 300 former Soviet Union Block studies, which had focused primarily on therapeutic/clinical applications of MMWs, as well as about 50 studies from other countries that had focused on public health effects. They were looking to close the gap between those very different orientations between countries. Much of the Soviet Block research had never previously been seen by Western scientists and because of the language barrier, as well as differences in test protocols, measurements, and reportage styles, Western scientists often dismissed Russian research as incomplete. The large review included effects from low-intensity exposures (MMWs 10 mW/cm^2 and less) in everything from molecules, microbes, and cells, to the unique qualities of water, resonance, and MMW therapy. Studies covered dosimetry/spectroscopy issues, as well as cell-free systems, cultured cells, and isolated organs in animals and humans. Pakhomov et al. [269] found effects to cell growth/proliferation, enzyme activity, genetic structures, excitable membrane function, peripheral receptors, and other biological systems. In human and animal models, local MMW therapeutic applications stimulated tissue repair and regeneration, alleviated stress reactions, and facilitated recovery from a wide range of diseases. Former Soviet Block countries claim to treat approximately 50 diseases with MMW. The reviewers reported that many effects could not be readily explained by temperature changes alone.

Some of the animal models with potential significance to wildlife cited in Pakhomov et al. [269] included: yeast: *Saccharomyces cerevisiae*, [294–298]; *Candida albicans* [299]; *barley seeds* [300]; protozoans *Spirostum* spp. [301]*;* blue-green algae *Spirulina platensisby* [302]; midge *Acricotopus lucidus* [303]; *Escherichia coli* [304]; rats [305]; frog/nerve cells [306–310]; antibiotic resistance to *Staphylococcus aureus* [311] and others.

Of particular challenge to the popular wisdom that MMWs are “safe” due to superficial skin penetration, is the research on peripheral nerve receptors cited in Pakhomov et al. [269]. Akoev et al. [312] studied MMW effects to the specialized electroreceptor cells called Ampullae of Lorinzini in anesthetized rays and found that the spontaneous firing in the afferent nerve fiber from the cells could be enhanced or inhibited by MMWs at 33–55 GHz continuous wave (CW). The most sensitive receptors increased firing rates at intensities of 1–4 mW/cm^2, which produced less than a 0.1 °C temperature increase. Higher intensities (10 mW/cm^2 and up) evoked delayed inhibition of firing, indicating that the response became biphasic. The authors emphasized they were not observing just a MMW bioeffect but rather a specific response to that frequency range by an electro-receptor cell.

Work also cited in Pakhomov et al. [269] regarding similar nerve cells/pathways and MMW-induced arrhythmia included a paper by Chernyakov et al. [307] where they observed induced heart rate changes in anesthetized frogs from MMW irradiation to remote skin areas. This suggested a reflex mechanism possibly involving specific peripheral receptors. Later, Potekhina et al. [313] similarly found that certain frequencies from 53–78 GHz band (CW) effectively changed the natural heart rate variability in anesthetized rats when applied to the upper thoracic vertebrae for 20 min at 10 mW/cm^2 or less. MMWs at 55 and 73 GHz caused pronounced arrhythmia: the variation coefficient of the regular rhythm (R-R) interval increased 4–5 times while exposure at 61 or 75 GHz had no effect, and other frequencies caused intermediate changes. Skin and whole-body temperatures remained unchanged. Similar frequency dependence was observed in additional experiments with 3 h exposures. However, approximately 25% of experiments were interrupted because of sudden animal death that occurred after 2.5 h of exposure at 51, 61, and 73 GHz. This body of work suggests that the link between superficial cellular effects and whole-organism effects — the least understood aspect of MMWs — may be due to peripheral receptors and afferent nerve signaling, leading to larger systemic reactions from what are assumed to be superficial exposures. This may prove particularly significant in non-human species.

While some of the above cited studies are at a higher power density than most of the focus in this paper, because of the ubiquity of millions of new antennas planned for 5G small cells, near-field exposures to wildlife, even in rural areas, are far more likely than from distant infrastructure.

In 2000, the U.S. Central Intelligence Agency declassified and released a compendium of theoretical and experimental papers, primarily from Russia, many already covered in Pakhomov et al. [269] on high frequency MMW and ELF studies. Cited works included a review of 6,000 papers by Kholodov [314] that appeared in Markov and Blank [315] demonstrating EMF interactions with a variety of animal and human biological systems. Effects were seen in the central nervous system with the degree of response dependent on myriad radiation parameters, including frequency, pulse shape and exposure duration. Wide ranging effects were documented from microbiota to mammals. They included: MMW effects on the central and peripheral nervous system [316] with a majority (80%) of human subjects detecting and being cognitively aware of exposures as low as 10 billionths of a W/cm^2, i.e., 10 nW/cm^2; 50 μ/W affected *Proteus* bacteria [317]; MMW as low as 1 μW/cm^2 within a very narrow frequency range (51.62 < vs. 51.85 GHz) induced changes in *E coli* bacteria, indicating a resonance response; and sharp resonances in HF/MMW ranges were seen, indicating that MMW act as a catalyst for intra- and inter-cellular communication. HF/MMW may trigger complex non-linear oscillations capable of affecting fundamental processes in whole living systems [270, 271, 318–324]. See below for more on MMW and nonlinear effects.

There are more updated reviews of the MMW frequency range [273, 325] with the most recent from Simko and Mattson [326] and Alekseev and Ziskin [327].

Simko and Mattson [326] focused on potential 5G safety and nonthermal effects. They investigated works (between 6 and 100 GHz MMW divided into seven ranges) for health impacts, analyzing 94 studies, characterized for type (*in vivo, in vitro)*; biological material (species, cell type, etc.); biological endpoints; exposure parameters (frequency, duration, power density); results; and critical study quality. They found 80% of *in vivo* studies and 58% of *in vitro* studies showed effects, with responses affecting all biological endpoints investigated. They also found no consistent relationship between power density, exposure duration, and frequency with exposure effects across the studies investigated although there were consistencies within some groupings for effects that were frequency dependent. They concluded that overall the studies did not provide adequate information to determine meaningful safety assessments, or to answer questions about non-thermal effects, adding there is a need for research on small surface local heating developments (e.g., skin or eyes), and on environmental impacts. They called for significant quality improvement in future study design and implementation. They also noted that no epidemiology studies exist for these frequency ranges — an important observation — and that it is important to investigate effects to wildlife as the depth of MMW penetration in very small organisms can result in potentially significant heating.

Alekseev and Ziskin [327] reviewed MMWs, sub-MMWs and THz ranges with close attention to skin properties/permittivity as well as other physiological endpoints in the early literature. Their focus was primarily on thermal intensities although some nonthermal works are included. They concluded that effects below thermal intensities were negligible.

One U.S. MMW study by Siegel and Pikov [328] at very-low-intensity produced effects far below regulatory standards. The authors noted the growing need to understand MMW mechanisms of interaction with biological systems for both adverse effects and therapeutic uses and said that independent of health impacts of long-term high-dose MMW exposure on whole organisms, that potential subtle effects on specific tissues or organs also exist. Their focus was on quantifying real-time changes in cellular function as energy was applied in a series of experiments. Effects found changes in cell membrane potential and the action potential firing rate of cortical neurons under short (1 min) exposures to continuous-wave 60 GHz radiation at mW/cm^2 power levels more than 1,000 times below the FCC maximum permissable exposure (MPE). After review of papers on neuronal activity in MMW frequencies at low intensities, Siegel and Pikov [328] examined MMW-induced apoptosis and transient membrane permeability in epithelial cells *in vitro*, as well as real-time changes in the activity and membrane permeability of individual pyramidal neurons in patch-clamp probed cortical slices. One study, using *in vitro* cerebral cortex slices from 13-to-16-day-old rat pups, was exposed to MMW 60 GHz (at 7.5, 15, 30, 60, 120 and 185 mW exposures) introduced in random sequences, held fixed for 1 min for three current cycles, then turned off. Bath temperature was constantly monitored with temperature rise between 0.1 to 3 °C. They found changes in firing at power levels of 0.3 μW/cm^2 and above after four different MMW power levels at approximately 0.1–1 mW/cm^2. Rise and decay slopes of individual action potentials and membrane resistance were also strongly correlated with MMW power levels indicating opening of membrane ion channels. They concluded that at power levels of approximately 300 nW/cm^2 and above, a strong inhibition of the action potential firing rate in some neurons existed, as well as an increased firing in others. This indicated possible functional heterogeneity in the studied neuronal population. Further they said that rise in bath temperature could not fully account for such dramatic changes in membrane permeability. These results are believed to be the first positive correlative measurements of real-time changes in neuronal activity with ultra-low-power MMW exposures. They said that although there was a lack of high-accuracy SAR data for each sample, further investigation was warranted as effects recorded were at levels well below recommended MPE's. Their findings also have therapeutic implications for non-contact stimulation and neurologic function control in suppression of peripheral neuropathic pain and other central neurological disorders.

There are hundreds of MMW studies at high intensities not included in this paper that may also be environmentally relevant to ambient near-field 5G exposures.

5G's unusual signaling characteristics: phased array, MIMO, Sommerfeld and Brillouin precursors

5G employs unusual signaling characteristics not broadly deployed before now. Phased array (multiple antennas that fire at different rates/times) has been used for decades in military radar and a few other industrial applications. Phased arrays can boost signal strength which in turn helps signals penetrate deeper into buildings. In its adaptation to civilian-based wireless networks, phased array is considered a unique characteristic that has not been well studied as a specific biologically active entity although that was called for over 20 years ago [329, 330]. However, enough research does exist in similar frequencies to raise safety questions. Still, all extrapolations for safety regarding 5G transmission designs have been made from inapplicably different radiation models for continuous (always-on) or pulsed (intermittently on) wave forms using single element or non-phased systems. While phased array is pulsed, it is a system in which the pulses overlap (thus the term "phased") which constitutes a unique biological exposure since there is no cellular recovery time between exposures. It is therefore in essence always "on."

Although not everyone agrees this is a unique enough characteristic to warrant further research or different safety considerations from what traditionally have been used [111, 112, 130, 131, 331, 332], there are nevertheless serious concerns regarding phasing because it interacts with living cells in extremely complex ways that have nothing to do with traditional thermal thresholds. The wave form itself is the biologically active component [329, 330, 333–338].

Phasing is created by multiple antennas and sub-antennas transmitting at simultaneous or slightly different intervals at different frequencies, creating what can become steep wave banks that interact with living cells from many different angles and time sequences. Because of varying impedance factors of radiation moving through air and microsecond differences in transmission rates, each antenna in a multiple radiating element reaches the body — human and non-human alike — at slightly different times, creating multiple overlapping wave fronts. Each wave front strikes from a slightly different location and/or angle, creating a characteristic sequence of layered modulation unlike any other electromagnetic propagation source. Nothing like this exists in nature. Although phased array has been around since the 1940s, it has not heretofore been used for broadband civilian telecommunications infrastructure or in widely used consumer devices until now.

5G is a combination of line-of-sight transmission with simultaneous ground-level side-lobe pulsed phased exposures, involving an incredibly complicated infrastructure with accompanying extensive ambient exposures from what is projected to be millions of new antennas in the U.S. alone. 5G will use phased broadband signals emitted in constant pulsed overlapping waves that gradually rise in frequency, simultaneously transmitted from slightly different locations and angles that build up in a kind of stair-step fashion. As designed, 5G will employ 'Massive' MIMO (multiple input, multiple output) compound-element transceivers — over 100 per physical antenna encasement — for simultaneous signal/data sending and receiving. Because the EHF frequency is higher on the electromagnetic spectrum with shorter wavelengths, individual antenna elements are smaller so more elements can be located in the same place. Multiple antenna elements are also necessary for phasing. In time, user devices will also contain EHF MIMO and phased array technology embedded in devices like iPhones, which already contain multiple antennas. 4G LTE technology already uses compound elements and although the two systems will be interdependent in the near future, 5G as designed is substantially different enough that new phones will eventually be needed.

In addition, 5G will employ beam steering technology (of which there are several types) that allow antennas to produce and focus very narrow beams in a specific direction. By concentrating and focusing the signal, the effective radiated power is boosted which means narrow signals can travel farther and more effectively penetrate buildings and other obstacles. Beam steering also allows antennas to direct signals to user devices rather than the 360° radiation patterns of omnidirectional antennas now commonly used in telecommunications infrastructure. Beam steering is accomplished by changing phases and/or switching antenna elements. To plot the best route between signal and user, highly advanced signal processing algorithms are required.

Proponents of 5G are enamored with the network's brilliant RF engineering and hypothesize that 5G will increase system efficiency, reduce RF interference from other sources, reduce overall ambient exposures because it is a highly directed network, and be faster and more energy efficient. But 5G's sheer scale will prove some of these projections incorrect and one industry estimate holds that 5G will require 10 times more energy than is used today for telecommunications [340]. Additionally, beam steering does not reduce ambient exposures with systems at such a scale. It does, however, with the densification of infrastructure create a whole new layer of novel RFR exposures.

Any exposure standards in place today being applied to 5G control mostly for near-field exposures. But phasing creates unpredictable far-field biological effects. With phased array transmission, the wave front arrival rate and buildup can increase as it moves away from the radiating source, creating multifaceted wideband dispersion/exposures ([341], see Figures 1 and 2 below), making exposures potentially more complex in far field environments in many different frequency ranges.

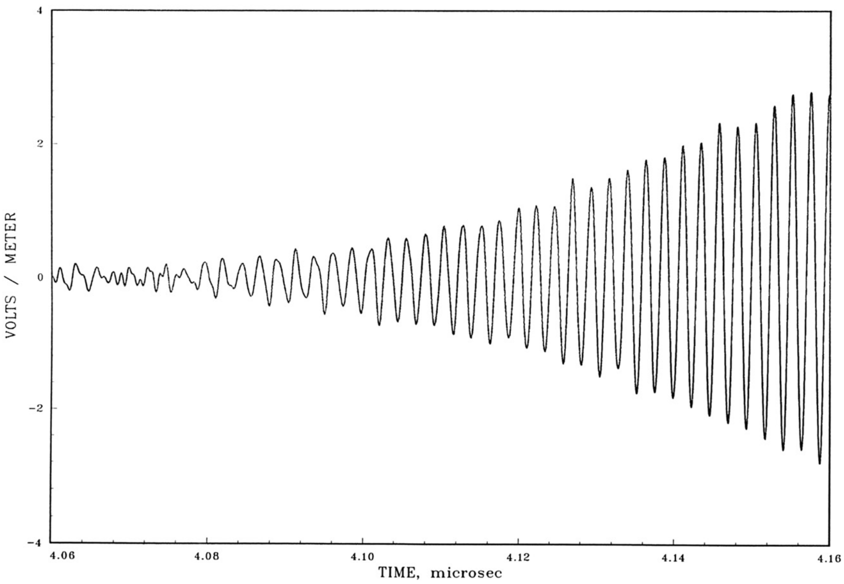

Figure 1: Phased array transmission can create wideband dispersion.
Near normal at the array face, buildup can occur as signal moves away from the generating source. Illustration shows how phased array radar buildup occurs in radar frequencies between 420 and 450 MHz [341]. From National Research Council, 2005. An Assessment of Potential Health Effects from Exposure to PAVE PAWS Low-Level Phased-Array Radiofrequency Energy, p 63. https://doi.org/10.17226/11205. Reproduced with permission from the National Academy of Sciences, Courtesy of the National Academies Press, Washington, D.C.

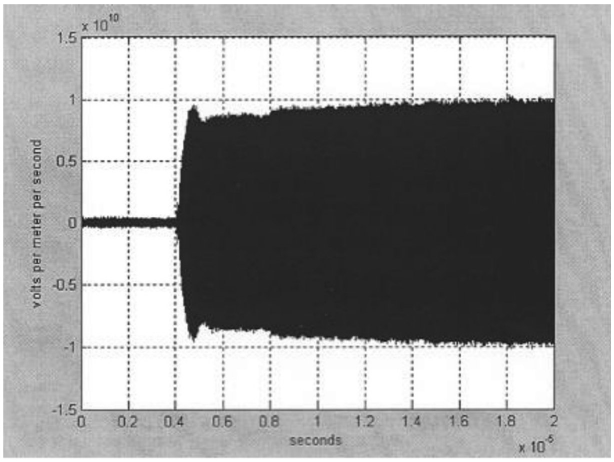

Figure 2: MMW bank buildup can also be near instantaneous.
At 500 m: the variation in slopes or rise times encountered through a pulse with many slopes being significantly greater than ±1 V per meter per nanosecond. Used with permission from Richard Albanese. Appeared in, An Assessment of Potential Health Effects from Exposure to PAVE PAWS Low-Level Phased-Array Radiofrequency Energy. National Research Council, 2005 p. 70. https://doi.org/10.17226/11205 [341].

The reason that phasing may have a unique biological impact is because very fast peak radiation pulses generate bursts of energy that can give rise to what are called Sommerfeld and Brillouin precursors in living cells that can in turn penetrate and disperse much deeper than traditional models predict [333–338, 339, 342–347]. Sommerfeld/Brillouin precursors most notably form with ultra wideband exposures as proposed with 5G.

Arnold Sommerfeld's [348] and Léon Brillouin's [349] writings on how wave fronts enter and move through 'lossy' materials (materials that absorb radiation like soil, water or living tissue) go back at least 100 years but their interest was in energy penetration and movement, not biological effects, and their orientation was on physics, not medicine. Sommerfeld and Brillouin's work noted that with the movement of a sinusoidal wave through a Lorentz medium, two transients formed. The first — now called the Sommerfeld precursor — travels at the speed of light and oscillates at very high frequencies, while the second — now called the Brillouin precursor — follows the first at slower speed. Oughstun and Sherman [339] established more current mathematical modeling for precursor formation. Both Sommerfeld and Brillouin precursors were observed in a waveguide apparatus by Plesko and Palotz [350]. The Sommerfeld precursor is estimated to have small amplitude in water-based materials like cells and tissue but has not actually been seen in such materials, while Brillouin precursors have been seen in water-based materials. Wide bandwidths in general — like 5G broadband which uses multiple frequencies — have been found to produce more precursors than narrow bandwidths; precursor formation is directly related to bandwidth (or rise time) and dispersion, but not always to electric field slope (V/m/nsec). Once generated, pulses can propagate without much attenuation and are thought to decay slowly only after significant attenuation has occurred in cellular media. That means precursors are long lasting in tissue. Precursors can occur any time during exposure [341].

With precursor formation, the salient factor is the speed at which energy is introduced. A slow introduction into material will not result in precursor formation. Precursors result from an external field being introduced at a rate faster than the motional response times of the medium itself [329, 351]. While typical continuous sinusoidal waves and pulsed exposures do not create wave fronts but are capable of causing thermoregulatory changes and other effects, phased array's sequence of wave fronts under certain circumstances may be capable of both thermoregulatory changes and electrostrictive perturbations thereby creating an unpredictable nonlinear feedback loop in living systems [329, 333–338, 351]. In other words, with 5G functioning in the EHF ranges with phased array signals, these are no longer simply physics theories. Precursors are capable of overwhelming living cells in highly unpredictable nonlinear patterns, potentially causing structural cellular fatigue and material changes throughout the entire organism.

According to Richard A. Albanese, M.D., (per. comm. 4/5/2021), when leading or trailing edge slopes (rise times) are ±1 V per meter per nanosecond or greater, a precursor will occur. Also when the signal spikes up or down such that the absolute difference between slopes/rise times is ±1 V per meter per nanosecond or greater, a precursor will occur. An example precursor is shown below in Figure 3.

Also note in Figure 3 that the slope/rise time caused by the precursor frequently exceeds ±5 V per meter per nanosecond – a factor of considerable concern. Of equal concern is that when such exposures are averaged the way that ICNIRP and FCC standards currently are (see Part 3), the slope/rise times theoretically "disappear" but not the actual biologically pertinent exposure itself in ambient field conditions.

With phased arrays, peak wave fronts arrive with time differentials in pico- and nanosecond ranges from multiple angles and distances. When wave fronts are sufficiently sharp, there is evidence that molecular re-radiation can occur as cell membrane potentials change. In other words, cells can function as small internal antennas [333, 339, 352, 353]. Wave fronts are thought to place energy quickly into molecules. When that happens, molecules are shown to re-radiate energy rather than produce heat according to the classic thermoregulatory models, and therefore travel deep into a living organism [339, 344, 347]. Rogers et al. [354] found that short pulses of 5 ns stimulated excised frog muscle contraction, demonstrating that wave fronts can depolarize membrane potentials. D'Ambrosio et al. [355] contrasted continuous waves with GMSK phased signals at 1.7 GHz and found a statistically significant rise in genotoxicity at the same SAR levels with phasing but not continuous waves.

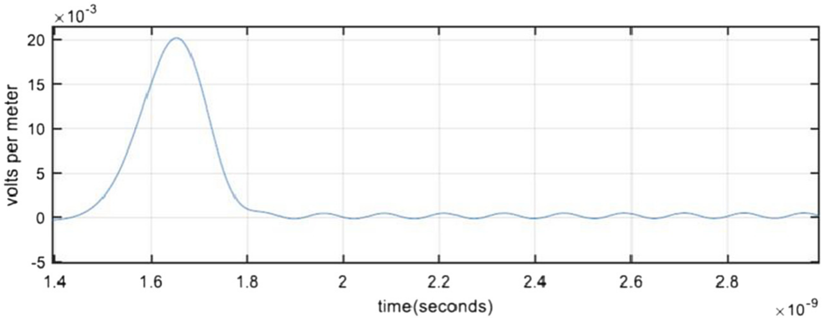

Figure 3: The above illustration shows a 20 mV precursor arising from a 1 V per meter square sinusoidal wave modulated at ~8 GHz. Of significance is the slope or rise time measured in volts per meter per nanosecond, not the carrier frequency. The above graph shows that the small amplitude of the carrier wave in tissue and the precursors that form can carry into the medium at a short duration direct-current level. However, if a sequence of these occurs – such as in phased exposures – and if the incident amplitudes are of higher magnitude, a living subject will receive a DC exposure that can depolarize cell membranes. Used with Permission by Richard A. Albanese.

Oughstun and colleagues have published many predictive mathematical and experimental papers on precursors,[1] especially those occurring in infrared (IR) laser waveforms. Infrared is visible to some species, especially birds, where it is thought to relate to breeding vigor. Although 5G is not yet licensed in IR wavebands, the upper ranges of EHF allocated for 5G are near the IR range with very similar biological effects; other technologies plan to use IR for communications purposes.

Similar observations to those described above regarding unusual propagation characteristics at these significantly higher frequencies have recently been made in studies of THz waves (between 0.3 and 30 THz in the far infrared range) by Yamazaki et al. [356]. They found that despite strong absorption by water molecules, the energy of THz pulses (250 μJ/cm^2) transmits at a millimeter thick in aqueous solution, possibly as a shockwave, and demolishes cellular actin filaments. Collapse of actin filaments induced by THz irradiation was also seen in living cells under an aqueous medium. They found that while the viability of the cell was not affected by THz pulses, the potential of THz waves as an invasive method to alter protein structure in the living cells still existed.

While our present paper does not include studies in the THz range, it is briefly mentioned here because technology in the THz range is already deployed in airport scanners and is planned for use in future Li-Fi wireless and some 5G applications [357]. The Yamazaki et al. [356] study in the THz range mentioned above challenges popular assumptions that THz radiation effects are negligible on deep tissues due to strong absorption by water molecules. The researchers found the potential opposite.

Satellites

The use of satellites for two-way broadband communications goes back to the 1960s for military applications, academic/government research, and weather prediction. Widespread adaptations for civilian use only began in the late 1980s and 1990s for radio/TV broadcast and Internet connectivity. Today civilian use has exploded, along with significant concerns.

Satellites cover entire regions, mostly broadcasting back toward Earth in both line-of-sight arrays and wide radiation patterns much like a flashlight's beam. The farther away the satellite, the broader the beam and higher the power density needed to reach Earth; some satellites transmit at millions of watts of effective radiated power. Satellites have the ability to reach rural and remote areas in ways terrestrial networks cannot, and therefore affect wildlife in ways that may never be detected.

There are already thousands of satellites circulating the Earth today. Like earth-base systems, the radiofrequency bands traditionally used for satellites have become so crowded that engineers are turning to two-way systems using laser frequencies. In 2013, the U.S. NASA Lunar Atmosphere and Dust Environment Explorer used a pulsed laser beam to transmit data over 239,000 mi (384,633 km) between the moon and Earth at a record-breaking download rate of 622 MB/s [358]. The laser frequencies are close to the upper ranges planned for 5G, and are visible to many species which see far broader light spectra than humans.

There are three general categories of satellites based on their height above the Earth's surface [359]. The first is in low Earth orbit (LEO) at about 111–1,243 mi (180–2,000 km, respectively) above Earth, used for Earth surface observations, military purposes and weather data. Medium Earth orbit (MEO) occurs at about 1,243–22,223 mi (2,000–36,000 km, respectively) used for navigation like GPS and telecommunications. High Earth orbit occurs at an altitude greater than 22,223 mi (36,000 km). High Earth orbits are also called geosynchronous orbits (GEO). Satellites there orbit every 24 h, the same as Earth's rotational period. GEO's can be fixed over one spot or circle elliptically. Some are aligned with the Earth's equator; others not. There are several hundred television, communications and weather satellites in geostationary orbits.

Space above us has now become very crowded. Satellites vary enormously in size, design, and construction according to their purpose. They are used for everything from weather-data gathering, communications (cell/Internet), broadcast radio/TV, scientific research, navigation, emergency rescue, Earth observation and military purposes. Many — though not all — weather and some communications satellites are in high Earth orbit; satellites in a medium Earth orbit include navigation and specialty satellites used to monitor a particular region, while most scientific satellites, including NASA's Earth Observing System fleet, have a low Earth orbit. A small number of satellites turn their attention (and radiation) toward space for research purposes.

There are many satellite companies, all with different models and configurations depending on their goals. Historically, satellites have relied on C band frequencies

---

[1] For a list of 30 Oughstun studies current to 2005, see An Assessment of Potential Health Effects from Exposure to PAVE PAWS Low-Level Phased-Array Radiofrequency Energy PAVE PAWS 2005, Annex 5-5, pp. 90–93. http://www.nap.edu/catalog/11205.html and Dr. Oughstun's website, www.emba.uvm.edu/~oughstun.

between the 4 and 8 GHz portion of the microwave range with the least amount of attenuation through Earth's atmosphere — best for long distance transmission. But that traditional range has a lower data-carrying capacity than today's demands, so increasingly the Ku band between 12 and 18 GHz and the Ka band between 26 and 40 GHz are being used. The 60 GHz band has been used by the military for satellite-to-satellite communication. Increasingly satellite systems like Telstar will use a combination: C band for wide area coverage mixed with higher frequency Ku and Ka bands for more focused spot beams, also called high-capacity beams. One apt analogy of this combination likens the human eye to the "wide view" whereas an insect's eye is a compound structure, like spot beams capable of pointing in different directions.

New complex multifrequency satellite networks are increasing and therefore Earth exposures are too. Large or small, most satellites communicate with earth-based stations at significant power outputs.

Recent increases in satellites

Today's entrepreneurs — including Elon Musk with SpaceX/Starlink, Jeff Bezos with Amazon's Project Kuiper, Mark Zukerberg with Facebook's Athena, Telestat in Canada, OneWeb in the UK, the Russian Roscosmos, the Hongyun Project in China, and several others — are extending satellite communication to 5G technology, employing thousands of new low-to- mid-earth orbiting satellites that will create another low-level layer of novel exposures that do not now exist. There have been no Environmental Assessments (EAs) or Environmental Impact Statements (EISs) reviewed under NEPA by the FCC, which determined in 1986 that satellites were categorically excluded ([360]; also see Part 3).

By 2021, Musk plans to have launched 1,584 satellites, with another 11,943 by 2025, in contrast to the approximate 1,500 in obit as recently as 2019 [361].The ultimate plan, if allowed by FCC, is for 42,000 Starlink satellites covering the globe (placed at three different atmospheric stratas: 211 mi/340 km, 342 mi/550 km, and 715 mi/1,150 km). In October 2019, Musk sought permission for 30,000 more, to orbit between 203 mi/328 km and 380 mi/614 km, using frequencies between 10.7 and 86 GHz in overlapping phased array cells — and that's just one provider [362]. As of this writing, SpaceX/Starlink has deployed 597 satellites with 14 more multi-satellite launches planned by 2021. About 500 are functioning, ready to provide internet to some locations on Earth [363].

The FCC also granted Starlink a 15-year license for up to one million fixed-earth user terminals to communicate with Starlink's network [364], plus the FCC granted temporary approval for test stations in six states (California, Minnesota, Idaho, Alabama, Georgia and Montana) as proof of concept in advance of Starlink's official commercial opening by the end of 2020. The company intends to use the 28.6–29.1 and 29.5–30.0 GHz spectra for uploading data from the Earth stations to Starlink satellites; and 17.8–18.6 and 18.8–19.3 GHz for downlinks [365]. In addition to Starlink, Amazon's Kuiper Systems won the endorsement of the FCC's chairman, Ajit Pai, in July 2020 for 3,236 new satellites [366].

Satellite transmission in the upper atmosphere has always suffered from cloud cover interference and high latency (the time for signal to get from one place to another). SpaceX's 5G Earth orbiting design bypasses some of these problems by putting satellites in low and very-low orbits above Earth, unlike typical internet satellites in geostationary orbit at or above 22,000 mi (35,405 km) [367]. Being closer to the ground means more satellites will be needed as each satellite will cover a smaller area. While SpaceX plans to create global Internet coverage with its initial deployments in low Earth orbit in the U.S., it will then fill in gaps with thousands more at very low Earth orbit (VLEO) at approximately 211 miles (340 km) above Earth. SpaceX plans to cover rural areas first which theoretically could affect wildlife that likely will go undetected.

The U.S. is also implementing the new U.S. Space Force under the Department of Defense (DOD) and will deploy five new missile-warning satellites by 2029 in high altitude stationary orbits [368]. Additionally, DOD will augment with satellites in low Earth orbits for hypersonic missile defense [369]. SpaceX is expected to handle 40% of national security satellites that will be deployed within the next decade [370].

There have been numerous negative comments to FCC from NGO's, businesses, government agencies, and legislators about this unprecedented commercial satellite increase, especially regarding projects earmarked for 5G civilian communications due to potential interference with other agencies' use of similar frequency bands for critical weather forecasting, GPS communications, and astronomy, among others. One focus has been on FCC's 2020 licensing of Ligado Networks' (formerly LightSquared) use of the L-Band for a national civilian mobile broadband network. The L-Band is spectrum for GPS used by the military, businesses, and consumers. FCC's decision is opposed by the Pentagon; numerous U.S. agencies including The Department of Transportation; professional organizations like the Air Line Pilots Association and the International Air Transport Association; and industries like Iridium Communications and Lockheed Martin. Thirty-two U.S. senators have also asked FCC to reconsider [371].

Comments to FCC include those from the National Oceanic and Atmospheric Administration (regarding weather forecasting and research), and the Department of Energy (regarding power grid security) among others. In January 2020, The International Astronomers Appeal was filed at FCC stating “extreme concern” over tens of thousands of satellites greatly outnumbering the 9,000 stars visible to the unaided human eye, permanently blocking visibility and altering astronomical research forever. They warned there could be over 50,000 small satellites encircling the Earth at different altitudes for telecommunications purposes, primarily 5G Internet connectivity. Night-time migrating species also use stars for orientation. This sudden infusion of artificial “stars” may have adverse effects that go undetermined.

None of these agencies or companies appear concerned about the massive infusion of novel RFR into various strata of the atmospheric or ground-based environment, and the U.S. Environmental Protection Agency — the agency with primacy over environmental radiation effects — has been defunded for nonionizing radiation research and regulatory oversight since 1996 [372].

Since the ionosphere is a dynamic system capable of nonlinear excitation from external stimulation, there are reasonable concerns that satellites may be contributing to atmospheric perturbation, climate change, and weather instability [373, 374]. In addition, oxygen (O_2) molecules readily absorb the 60 GHz frequency range and rain easily attenuates signals [208, 209, 375]. At 60 GHz, 98% of transmitted energy is absorbed by atmospheric oxygen. This makes that frequency spectrum good for short-range transmission but no one understands how a large infusion of RFR in that band — or any other — may affect atmospherics. It could be highly destabilizing [376].

The FCC has allocated MMW from 57.05-to-64 GHz for unlicensed use. While all wireless equipment operating at 60 GHz must obtain FCC certification, once certified, products can be deployed license-free throughout the United States [209]. This frequency band may prove popular for myriad uses. It may also be capable of destabilizing both local micro-climate weather systems as well as broader atmospheric events due to maximal coupling with oxygen and resonance factors with water molecules [208].

By the time satellite transmissions reach the Earth’s surface, the power density is low but with 5G’s phased array signals, the biologically active component is in the waveform, not power density alone. There is no research to predict how this will affect wildlife in remote areas but given what is known about extreme sensitivity to EMFs in many species, it is likely that effects will occur and likely go undetected. Because much of the research on phased array and precursors has been done in lossy materials like water, we have models to suggest that 5G may have particular effects not only on insect populations (due to resonance factors) and amphibians (due to thin membranes and deep body penetration) but also in some aqueous species since water is a highly conductive medium. Even weak signals from satellites using phased array characteristics may be a significant contributor to species effects in remote regions.

There have been no EAs or EISs conducted through NEPA reviews to study this [377]. FCC exempted satellites from NEPA review in 1986 [360] largely based on the fact that NEPA applies to the human environment and satellites are far away. There appears to be no specific mention of satellites being specifically exempt from NEPA but the tradition of exemption continues to the present [378] although the FCC is being asked to reconsider [379].

Conclusion

Ambient background levels of EMF have risen sharply in the last four decades, creating a novel energetic exposure that previously did not exist at the Earth’s surface, lower atmospheric levels, or underwater environments. Recent decades have seen exponential increases in nearly all environments, including remote regions. There is comprehensive but outdated baseline data from the 1980s against which to compare significant new surveys from other countries which found increasing RFR levels in urban, suburban and remote areas, primarily from cell infrastructure/phone/WiFi exposures. One indicative comparison of similar sites between 1980 and today found a 70-fold (7,000%) increase in ambient RFR [149]. The increased infrastructure required for 5G networks will widely infuse the environment with new atypical exposures, as are increasing satellite systems communicating with ground-based civilian networks. The new information provides broader perspective with more precise data on both potential transient and chronic exposures to wildlife and habitats. Biological effects have been seen broadly across all taxa at vanishingly low intensities comparable to today’s ambient exposures as examined in Part 2. The major question presented in Part 1 was whether increasing anthropogenic environmental EMF can cause biological effects in wildlife that may become more urgent with 5G technologies, in addition to concerns over potentially more lenient allowances being considered by major standards-setting committees at FCC and ICNIRP (examined in Part 3). There are unique signaling characteristics inherent to 5G transmission as currently designed of particular concern to non-human species. Background levels continue to rise but no one is studying cumulative effects to nonhuman species.

Research funding: None declared.
Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.
Competing interests: The authors declare no conflicts of interest.
Informed consent: Not applicable.
Ethical approval: Not applicable.

References

1. World Health Organization, International Agency for Research on Cancer, IARC 2002. Monographs on the evaluation of carcinogenic risks to humans, non-ionizing radiation, part 1, static and extremely low-frequency (ELF) electric and magnetic fields. Lyon, France: IARC Press; 2002, vol 80:338 p.
2. World Health Organization, International Agency for Research on Cancer, IARC 2012. Monographs on the evaluation of carcinogenic risks to humans, non-ionizing radiation, non-ionizing radiation, part 2: radiofrequency electromagnetic fields. Lyon, France: IARC Press; 2012, vol 102:419 p.
3. Balmori A. The effects of microwave radiation on wildlife, preliminary results; 2003. Available from: http://www.emrpolicy.org/litigation/case_law/beebe_hill/balmori_wildlife_study.pdf.
4. Balmori A. Electromagnetic pollution from phone masts. Effects on wildlife. Pathophysiology 2009;16:191–9.
5. Balmori A. The incidence of electromagnetic pollution on wild mammals: a new "poison" with a slow effect on nature? Environmentalist 2010;30:90–7.
6. Balmori A. Electrosmog and species conservation. Sci Total Environ 2014;496:314–6. 10.1016/j.scitotenv.2014.07.061.
7. Balmori A. Anthropogenic radiofrequency electromagnetic fields as an emerging threat to wildlife orientation. Sci Total Environ 2015;518–519:58–60.
8. Balmori A. Radiotelemetry and wildlife: highlighting a gap in the knowledge on radiofrequency radiation effects. Sci Total Environ 2016;543:662–9.
9. Cucurachi S, Tamis WLM, Vijver MG, Peijnenburg WLGM, Bolte JFB, de Snoo GR. A review of the ecological effects of radiofrequency electromagnetic fields (RF-EMF). Environ Int 2013;51:116–40.
10. Everaert J. Electromagnetic radiation (EMR) in our environment; 2016. Available from: www.livingplanet.be.
11. Krylov VV, Izyumov Yu G, Izekov EI, Nepomnyashchikh VA. Magnetic fields and fish behavior. Biol Bull Rev 2014;4:222–31.
12. Panagopoulos DJ, Margaritis LH. Mobile telephony radiation effects on living organisms. In: Harper AC, Buress RV, editors. Mobile telephones. Hauppauge, NY, USA: Nova Science Publishers, Inc.; 2008, Chapter 3:107–49 pp.
13. Sivani S, Sudarsanam D. Impacts of radio-frequency electromagnetic field (RF-EMF) from cell phone towers and wireless devices on biosystem and ecosystem – a review. Biol Med 2013;4:202–16.
14. Tricas T, Gill A. Effects of EMFs from undersea power cables on elasmobranchs and other marine species. Camarillo, CA: Normandeau Associates, Exponent; U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Pacific OCS Region; 2011 (OCS Study BOEMRE 2011-09).
15. Balmori A. Possible effects of electromagnetic fields from phone masts on a population of white stork (*Ciconia ciconia*). Electromagn Biol Med 2005;24:109–19.
16. Balmori A, Hallberg O. The urban decline of the house sparrow (*Passer domestics*): a possible link with electromagnetic radiation. Electromagn Biol Med 2007;26:141–51.
17. Engels S, Schneider NL, Lefeldt N, Hein CM, Zapka M, Michalik A, et al. Anthropogenic electromagnetic noise disrupts magnetic compass orientation in a migratory bird. Nature 2014;509:353–6.
18. Everaert J, Bauwens D. A possible effect of electromagnetic radiation from mobile phone base stations on the number of breeding house sparrows (*Passer domesticus*). Electromagn Biol Med 2007;26:63–72.
19. Fernie KJ, Bird DM. Evidence of oxidative stress in American kestrels exposed to electromagnetic fields. Environ Res 2001;86:198–207.
20. Fernie KJ, Reynolds SJ. The effects of electromagnetic fields from power lines on avian reproductive biology and physiology: a review. J Toxicol Environ Health B Crit Rev 2005;8:127–40.
21. Fernie KJ, Bird DM, Petitclerc D. Effects of electromagnetic fields on photophasic circulating melatonin levels in American kestrels. Environ Health Perspect 1999;107:901–4.
22. Fernie KJ, Bird DM, Dawson RD, Lague PC. Effects of electromagnetic fields on the reproductive success of American kestrels. Physiol Biochem Zool 2000;73:60–5.
23. Fernie KJ, Leonard NJ, Bird DM. Behavior of free-ranging and captive American kestrels under electromagnetic fields. J Toxicol Environ Health, Part A 2000;59:597–603.
24. Ritz T, Thalau P, Phillips JB, Wiltschko R, Wiltschko W. Resonance effects indicate a radical pair mechanism for avian magnetic compass. Nature 2004;429:177–80.
25. Ritz T, Wiltschko R, Hore PJ, Rodgers CT, Stapput K, Thalau P, et al. Magnetic compass of birds is based on a molecule with optimal directional sensitivity. Biophys J 2009;96:3451–7.
26. Tanner JA. Effect of microwave radiation on birds. Nature 1966;210:636.
27. Tanner JA, Romero-Sierra C, Davie SJ. Non-thermal effects of microwave radiation on birds. Nature 1967;216:1139.
28. Wiltschko R, Wiltschko W. Sensing magnetic directions in birds: radical pair processes involving cryptochrome. Biosensors 2014;4:221–43.
29. Wiltschko W, Wiltschko R. Magnetoreception in birds: two receptors for two different tasks. J Ornithol 2007;148:S61–76.
30. Wiltschko W, Munro U, Beason RC, Ford H, Wiltschko R. A magnetic pulse leads to a temporary deflection in the orientation of migratory birds. Experientia 1994;50:697–700.

31. Wiltschko W, Freire R, Munro U, Ritz T, Rogers L, Thalau P, et al. The magnetic compass of domestic chickens, *Gallus gallus*. J Exp Biol 2007;210:2300–10.
32. Wiltschko R, Thalau P, Gehring D, Nießner C, Ritz T, Wiltschko W. Magnetoreception in birds: the effect of radio-frequency fields. J R Soc Interface 2015;12:20141103.
33. Fedrowitz M. Cows: a big model for EMF research, somewhere between vet-journals and "nature". Bioelectromagnetics Society. Available from: https://www.bems.org/node/14835.
34. Löscher W. Survey of effects of radiofrequency electromagnetic fields on production, health and behavior of farm animals. Der Prakt Tierarzt 2003;84:11 (in German).
35. Löscher W, Käs G. Behavioral abnormalities in a dairy cow herd near a TV and radio transmitting antenna. Der Prakt Tierarzt 1998; 79:437–44 (in German).
36. Nicholls B, Racey PA. Bats avoid radar installations: could electromagnetic fields deter bats from colliding with wind turbines? PloS One 2007;2:e297.
37. Nicholls B, Racey PA. The aversive effect of electromagnetic radiation on foraging bats: a possible means of discouraging bats from approaching wind turbines. PloS One 2009;4:e6246.
38. Rodriguez M, Petitclerc D, Burchard JF, Nguyen DH, Block E, Downey BR. Responses of the estrous cycle in dairy cows exposed to electric and magnetic fields (60 Hz) during 8-h photoperiods. Anim Reprod Sci 2003;15:11–20.
39. Balmori A. Electromagnetic radiation as an emerging driver factor for the decline of insects. Sci Total Environ 2021;767:144913.
40. Cammaerts MC, De Doncker P, Patris X, Bellens F, Rachidi Z, Cammaerts D. GSM 900 MHz radiation inhibits ants' association between food sites and encountered cues. Electromagn Biol Med 2012;31:151–65.
41. Cammaerts MC, Rachidi Z, Bellens F, De Doncker P. Food collection and response to pheromones in an ant species exposed to electromagnetic radiation. Electromagn Biol Med 2013;32:315–32.
42. Cammaerts MC, Vandenbosch GAE, Volski V. Effect of short-term GSM radiation at representative levels in society on a biological model: the ant *Myrmica sabuleti*. J Insect Behav 2014;27:514–26.
43. Greggers U, Koch G, Schmidt V, Dürr A, Floriou-Servou A, Piepenbrock D, et al. Reception and learning of electric fields in bees. Proc R Soc B Biol Sci 2013;280:20130528.
44. Guerra P, Gegear RJ, Reppert SM. A magnetic compass aids monarch butterfly migration. Nat Commun 2014;5:4164.
45. Kirschvink JL, Padmanabha S, Boyce CK, Oglesby J. Measurement of the threshold sensitivity of honeybees to weak, extremely low-frequency magnetic fields. J Exp Biol 1997;200:1363–8.
46. Kumar NR, Sangwan S, Badotra P. Exposure to cell phone radiations produces biochemical changes in worker honey bees. Toxicol Int 2011;18:70–2.
47. Lazaro A, Chroni A, Tscheulin T, Devalez J, Matsoukas C, Petanidou T. Electromagnetic radiation of mobile telecommunication antennas affects the abundance and composition of wild pollinators. J Insect Conserv 2016;20: 315–24.
48. Odemer R, Odemer F. Effects of radiofrequency electromagnetic radiation (RF-EMF) on honey bee queen development and mating success. Sci Total Environ 2019;661:553–62.
49. Panagopoulos DJ, Margaritis LH. Effects of electromagnetic fields on the reproductive capacity of D. melanogaster. In: Stavroulakis P, editor. Biological effects of electromagnetic fields. New York, NY, USA: Springer International Publishing; 2003:545–78 pp.
50. Panagopoulos DJ, Karabarbounism A, Margaritis LH. Effect of GSM 900-MHz mobile phone radiation on the reproductive capacity of *Drosophila melanogaster*. Electromagn Biol Med 2004;23:29–43.
51. Sutton GP, Clarke D, Morley EL, Robert D. Mechanosensory hairs in bumble bees (*Bombus terrestris*) detect weak electric fields. Proc Natl Acad Sci USA 2016;113:7261–5.
52. Vácha M, Puzová T, Kvícalová M. Radio frequency magnetic fields disrupt magnetoreception in American cockroach. J Exp Biol 2009;212:3473–7.
53. Vargová B, Kurimský J, Cimbala R, Kosterec M, Majláth I, Pipová N, et al. Ticks and radio-frequency signals: behavioural response of ticks (Dermacentor reticulatus) in a 900 MHz electromagnetic field. Syst Appl Acarol 2017;22:683–93.
54. Vargová B, Majláth I, Kurimský J, Cimbala R, Kosterec M, Tryjanowski P, et al. Electromagnetic radiation and behavioural response of ticks: an experimental test. Exp Appl Acarol 2018;75: 85–95.
55. Cammaerts MC, Debeir O, Cammaerts R. Changes in *Paramecium caudatum* (Protozoa) near a switched-on GSM telephone. Electromagn Biol Med 2011;30:57–66.
56. Cellini L, Grande R, Di Campli E, Di Bartolomeo S, Di Giulio M, Robuffo L, et al. Bacterial response to the exposure of 50 Hz electromagnetic fields. Bioelectromagnetics 2008;29:302–11.
57. Movahedi MM, Nouri F, Golpaygani AT, Ataee L, Amani S, Taheri M. Antibacterial susceptibility pattern of the *Pseudomonas aeruginosa* and *Staphylococcus aureus* after exposure to electromagnetic waves emitted from mobile phone simulator. J Biomed Phys Eng 2019;9:637–46.
58. Potenza L, Ubaldi L, De Sanctis R, De Bellis R, Cucchiarini L, Dachà M. Effects of a static magnetic field on cell growth and gene expression in *Escherichia coli*. Mutat Res 2004;561:53–62.
59. Rodriguez-de la Fuente AO, Gomez-Flores R, Heredia-Rojas JA, Garcia-Munoz EM, Vargas-Villarreal J, Hernandez-Garcia ME, et al. *Trichomonas vaginalis* and *Giardia lamblia* growth alterations by low-frequency electromagnetic fields. Iran J Parasitol 2019;14:652–6.
60. Said-Salman IH, Jebaii FA, Yusef HH, Moustafa ME. Evaluation of Wi-Fi radiation effects on antibiotic susceptibility, metabolic activity and biofilm formation by *Escherichia coli* 0157H7, *Staphylococcus aureus* and *Staphylococcus epidermis*. J Biomed Phys Eng 2019;9:579–86.
61. Salmen SH, Alharbi SA, Faden AA, Wainwright M. Evaluation of effect of high frequency electromagnetic field on growth and antibiotic sensitivity of bacteria. Saudi J Biol Sci 2018;25:105–10.
62. Balmori A. Mobile phone mast effects on common frog (*Rana temporaria*) tadpoles: the city turned into a laboratory. Electromagn Biol Med 2010;29:31–5.
63. Balmori A. The incidence of electromagnetic pollution on the amphibian decline: is this an important piece of the puzzle? Toxicol Environ Chem 2006;88:287–99.
64. Komazaki S, Takano K. Induction of increase in intracellular calcium concentration of embryonic cells and acceleration of morphogenetic cell movements during amphibian gastrulation by a 50-Hz magnetic field. J Exp Zool 2007;307A:156–62.
65. Phillips JB, Deutschlander ME, Freake MJ, Borland SC. The role of extraocular photoreceptors in newt magnetic compass orientation: evidence for parallels between light–dependent

magnetoreception and polarized light detection in vertebrates. J Exp Biol 2001;204:2543–52.

66. Phillips JB, Jorge PE, Muheim R. Light-dependent magnetic compass orientation in amphibians and insects: candidate receptors and candidate molecular mechanisms. J R Soc Interface 2010;7(2 Suppl):S241–56.
67. Shakhparonov VV, Ogurtsov SV. Marsh frogs, *Pelophylax ridibundus*, determine migratory direction by magnetic field. J Comp Physiol A 2017;203:35–43.
68. Josberger E, Hassanzadeh P, Deng PY, Sohn J, Rego M, Amemiya C, et al. Proton conductivity in ampullae of Lorenzini jelly. Sci Adv 2016;2:e1600112.
69. Landler L, Painter MS, Youmans PW, Hopkins WA, Phillips JB. Spontaneous magnetic alignment by yearling snapping turtles: rapid association of radio frequency dependent pattern of magnetic input with novel surroundings. PloS One 2015;10: e0124728.
70. Lohmann KJ, Lohmann CMF. Detection of magnetic field intensity by sea turtles. Nature 1966;380:59–61.
71. Lohmann KJ, Lohmann CMF. Orientation and open-sea navigation in sea turtles. J Exp Biol 1996;199:73–81.
72. Lohmann KJ, Lohmann CMF. Migratory guidance mechanisms in marine turtles. J Avian Biol 1998;29:585–96.
73. Lohmann KJ, Witherington BE, Lohmann CMF, Salmon M. Orientation, navigation, and natal beach homing in sea turtles. In: Lutz P, Musick J, editors. The biology of sea turtles. Boca Raton: CRC Press; 1997:107–35 pp.
74. Luschi P, Benhamou S, Girard C, Ciccione S, Roos D, Sudre J, et al. Marine turtles use geomagnetic cues during open-sea homing. Curr Biol 2007;17:126–33.
75. Merrill MW, Salmon M. Magnetic orientation by hatchling loggerhead sea turtles (*Caretta caretta*) from the Gulf of Mexico. Mar Biol 2010;158:101–12.
76. Naisbett-Jones LC, Putman NF, Stephenson JF, Ladak S, Young KA. A magnetic map leads juvenile European eels to the Gulf Stream. Curr Biol 2017;27:1236–40.
77. Naisbett-Jones LC, Putman NF, Scanlan MM, Noakes DL, Lohmann KJ. Magnetoreception in fishes: the effect of magnetic pulses on orientation of juvenile Pacific salmon. J Exp Biol 2020;223: jeb222091.
78. Putman NF, Jenkins ES, Michielsens CG, Noakes DL. Geomagnetic imprinting predicts spatio-temporal variation in homing migration of pink and sockeye salmon. J R Soc Interface 2014;11: 20140542.
79. Putman NF, Meinke AM, Noakes DL. Rearing in a distorted magnetic field disrupts the ‘map sense’ of juvenile steelhead trout. Biol Lett 2014;10:20140169.
80. Putman NF, Scanlan MM, Billman EJ, O’Neil JP, Couture RB, Quinn TP, et al. Inherited magnetic map guides ocean navigation in juvenile Pacific salmon. Curr Biol 2014;24: 446–50.
81. Putman NF, Williams CR, Gallagher EP, Dittman AH. A sense of place: pink salmon use a magnetic map for orientation. J Exp Biol 2020;223:jeb218735.
82. Quinn TP, Merrill RT, Brannon EL. Magnetic field detection in Sockeye salmon. J Exp Zool 2005;217:137–42.
83. Belyavskaya NA. Ultrastructure and calcium balance in meristem cells of pea roots exposed to extremely low magnetic fields. Adv Space Res 2001;28:645–50.
84. Vian A, Roux D, Girard S, Bonnet P, Paladian F, Davies E, et al. Microwave irradiation affects gene expression in plants. Plant Signal Behav 2006;1:67–70.
85. Vian A, Davies E, Gendraud M, Bonnet P. Plant responses to high frequency electromagnetic fields. BioMed Res Int 2016;2016: 1830262.
86. NRDC. The promise of the smart grid: goals, policies, and measurement must support sustainability benefits. Issue brief, ralph cavanagh; 2012. Available from: https://www.nrdc.org/resources/promise-smart-grid-goals-policies-and-measurement-must-support-sustainability-benefits.
87. Sierra Club. Energy committee educates the public with smart grid forum, by rick nunno and amy weinfurter; 2013. Available from: https://www.sierraclub.org/dc/blog/2013/10/energy-committee-educates-public-smart-grid-forum.
88. Connecticut Department of Energy and Environmental Protection. Comprehensive energy strategy, CT general statutes section 16a-3d, Connecticut department of energy and environmental protection, draft; 2017. Available from: http://www.ct.gov/deep/lib/deep/energy/ces/2017_draft_comprehensiveenergystrategy.pdf.
89. Wheeler T. Prepared remarks of FCC Chairman Tom Wheeler, the future of wireless: a vision for U.S. leadership in a 5G world. Washington, D.C.: National Press Club; 2016:3 p.
90. Michaelson SM, Lin JC. Biological effects and health implications of radiofrequency radiation. New York and London: Plenum Press; 1987:272–7 pp.
91. Yong E. Robins can literally see magnetic fields, but only if their visions is sharp. DiscoverMagazine.com. Available from: http://blogs.discovermagazine.com/notrocketscience/2010/07/08/robins-can-literally-see-magnetic-fields-but-only-if-their-vision-is-sharp/#.WlU2d3lG3Z4.
92. Council of Europe, Parliamentary Assembly, Resolution 1815. Final version: the potential dangers of electromagnetic fields and their effect on the environment. Origin – text adopted by the standing committee, acting on behalf of the assembly, on 27 May 2011 (see doc. 12608, report of the committee on the environment, agriculture and local and regional affairs, rapporteur: Mr Huss); 2011. Available from: http://assembly.coe.int/nw/xml/XRef/Xref-XML2HTML-en.asp?fileid=17994&.
93. Health Council of the Netherlands. Report 2020. 5G and health to: the President of the house of representatives of the Netherlands. The Hague; 2020, No. 2020/16e.
94. Manville AM II. Recommendations for additional research and funding to assess impacts of nonionizing radiation to birds and other wildlife. Memorandum to Dr. J. McGlade, science advisor to United Nations Environment Program, key research needs affecting wildlife suggesting UNEP’s immediate attention; 2015:2 p.
95. Manville AM II. Impacts to birds and bats due to collisions and electrocutions from some tall structures in the United States — wires, towers, turbines, and solar arrays: state of the art in addressing the problems. In: Angelici FM, editor. Problematic wildlife: a cross-disciplinary approach. New York, NY, USA: Springer International Publishing; 2016, Chap. 20: 415–42 pp.
96. Manville AM II. A briefing memo: what we know, can infer, and don’t yet know about impacts from thermal and non-thermal non-ionizing radiation to birds and other wildlife — for public release. Peer-reviewed briefing memo; 2016:12 p.

97. Manville, AM II. Recommendations for additional research and funding to assess impacts of nonionizing radiation to birds and other wildlife. Memorandum to Dr. J. McGlade, science advisor to United Nations Environment Program, key research needs affecting wildlife suggesting UNEP's immediate attention; 2015:2 p.
98. Manville AM II. Protocol for monitoring the impacts of cellular communication towers on migratory birds within the Coconino, Prescott, and Kaibab National Forests, Arizona. Peer-reviewed research monitoring protocol requested by and prepared for the U.S. Forest Service. Division of Migratory Bird Management, USFWS; 2002:9 p.
99. Manville AM II. Anthropogenic-related bird mortality focusing on steps to address human-caused problems. In: Invited white paper for the anthropogenic panel, 5th international partners in flight conference, August 27, 2013. Division of Migratory Bird Management, USFWS, Snowbird, Utah; 2013:16 p. peer-reviewed white paper.
100. Levitt BB, Lai H. Biological effects from exposure to electromagnetic radiation emitted by cell tower base stations and other antenna arrays. Environ Rev 2010;18:369–95.
101. Sage C, Carpenter DO, editors. BioInitiative report: a rationale for a biologically-based public exposure standard for electromagnetic fields (ELF and RF). Report updated: 2014–2020; 2012. Available from: www.bioinitiative.org.
102. Mckinley GM, Charles DR. Certain biological effects of high frequency fields. Science 1930;71:490.
103. Ark PA, Parry W. Application of high-frequency electrostatic fields in agriculture. Q Rev Biol 1940;16:172.
104. McRee DI. A technical review of the biological effects of non-ionizing radiation. Washington, DC: Office of Science and Technology Policy; 1978.
105. Massey K. The challenge of nonionizing radiation: a proposal for legislation. Duke Law J 1979:105. https://doi.org/10.2307/1372226.
106. BENER. Nonionizing electromagnetic radiation (D-300 GHz). Report prepared for the National Telecommunications and Information Administration by the Interagency Task Force on biological effects of nonionizing electromagnetic radiation; 1979.
107. Havas M. From zory glaser's archive; 2010. Available from: http://www.magdahavas.com/introduction-to-from-zorys-archive/.
108. Foster KR, Morrissey JJ. Thermal aspects of exposure to radiofrequency energy: report of a workshop. Int J Hyperther 2011;27:307–9.
109. Foster KR, Kritikos HN, Schwan HP. Effect of surface cooling and blood flow on the microwave heating of tissue. IEEE Trans Biomed Eng 1978;25:313–6.
110. Foster KR, Ziskin MC, Balzano QR. Thermal response of human skin to microwave energy: a critical review. Health Phys 2016; 111:528–41.
111. Foster KR, Ziskin MC, Balzano QR. Thermal modeling for the next generation of radiofrequency exposures limits: commentary. Health Phys 2017;113:41–53.
112. Foster KR, Ziskin MC, Balzano Q, Bit-Babik G. Modeling tissue heating from exposure to radiofrequency energy and relevance of tissue heating to exposure limits: heating factor. Health Phys 2018:115295–307.
113. Justesen DR, Ragan HA, Rogers LE, Guy WA, Hjeresen DL, Hinds WT, et al. Compilation and assessment of microwave bioeffects: A selective review of the literature on biological effects of microwaves in relation to the satellite power system, no PNL-2634 (Revision). Washington, DC: Department of Energy; 1978.
114. Glasser ZR, Cleveland RF, Keilman JK. Bioeffects, chapter 3, NIOSH draft criteria document on radio-frequency and microwave radiation. Washington, DC [Director's Draft]: National Institute for Occupational Safety and Health; 1979: 29–330 pp.
115. American National Standards Institute, ANSI C95.1. American national standard safety levels with respect to human exposure to radio frequency electromagnetic fields, 300 kHz to 100 GHz. ANSI C95.1 – 1982; 1982. Available from: https://ehtrust.org/wp-content/uploads/2015/11/ANSI-National-standards-1982-safety-levels-for-human-exposure.pdf.
116. Federal Communications Commission. Evaluating compliance with FCC-specified guidelines for human exposure to radiofrequency radiation, 97–101th ed. Washington, DC: U.S. Federal Communications Commission. Office of Engineering and Technology, OET Bulletin 65; 1997. Available from: https://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet65/oet65.pdf.
117. U.S. Federal Communications Commission. Human exposure to radiofrequency electromagnetic fields and reassessment of FCC radiofrequency exposure limits and policies. A rule by the federal communications commission on 04/01/2020 published in: the federal register; 2020. Available from: https://www.federalregister.gov/documents/2020/04/01/2020-02745/human-exposure-to-radiofrequency-electromagnetic-fields-and-reassessment-of-fcc-radiofrequency.
118. U.S. Federal Communications Commission. (Federal register, human exposure to radiofrequency electromagnetic fields; correction, A proposed rule by the federal communications commission on 05/04/2020; 2020. Available from: https://www.federalregister.gov/documents/2020/05/04/2020-08738/human-exposure-to-radiofrequency-electromagnetic-fields-correction.
119. ICNIRP. Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). Germany: International Council on Non-Ionizing Radiation (ICNIRP). Oberschleisseim; 1998.
120. ICNIRP. International commissions on non-ionizing radiation protection, 2020 ICNIRP guidelines for limiting exposure to electromagnetic fields (100 KHZ TO 300GHZ), published ahead of print in health physics; 2020. Available from: https://www.icnirp.org/cms/upload/publications/ICNIRPrfgdl2020.pdf.
121. Magras IN, Xenos TD. RF-induced changes in the prenatal development of mice. Bioelectromagnetics 1997;18:455–61.
122. Schwarze S, Schneibder NL, Reichl T, Dreyer D, Lefeldt N, Engels S, et al. Weak broadband electromagnetic fields are more disruptive to magnetic compass orientation in a night-migratory songbird (*Erithacus rubecula*) than strong narrow-band fields. Front Behav Neurosci 2016;10:55.
123. Zosangzuali M, Lalremruati M, Lalmuansangi C, Nghakliana F, Pachuau L, Bandara P, et al. Effects of radiofrequency electromagnetic radiation emitted from a mobile phone base station on the redox homeostasis in different organs of Swiss

albino mice. Electromagn Biol Med 2021 Mar 9. https://doi.org/10.1080/15368378.2021.1895207 [Epub ahead of print].

124. Adey WR. Tissue interactions with nonionizing electromagnetic fields. Physiol Rev 1981;61:435–514.
125. Adey WR. Ionic nonequilibrium phenomena in tissue interactions with electromagnetic fields. In: Illinger KH, editor. Biological effects of nonionizing radiation. Washington, D.C.: American Chemical Soc.; 1981:271–97 pp.
126. Adey WR. Nonlinear, nonequilibrium aspects of electromagnetic field interactions at cell membranes. In: Adey WR, Lawrence AF, editors. Nonlinear electrodynamics in biological systems. New York: Plenum Press; 1984:3–22 pp.
127. Adey WR. Biological effects of electromagnetic fields. J Cell Biochem 1993;51:410–6.
128. Gandhi OP. The ANSI radio frequency safety standard: its rationale and some problems. IEEE Eng Med Biol Mag 1987;6: 22–5.
129. Frey AH, editor. On the nature of electromagnetic field interactions with biological systems. Austin, TX: R.G. Landes Company; 1994:5–6 pp.
130. Adair RK. Environmental objections to the PAVE PAWS radar system: a scientific review. Radiat Res 2003;159:128–34.
131. Adair RK. Biophysical limits on athermal effects of RF and microwave radiation. Bioelectromagnetics 2003;24:39–48.
132. Bruno WJ. What does photon energy tell us about cellphone safety? 2011. *arXiv preprint arXiv:1104.5008*. Available from: https://arxiv.org/abs/1104.5008 [updated 2017].
133. Becker RO. Cross currents, the perils of electropollution, the promise of electromedicine. Los Angeles: Jeremy Tarcher; 1990: 67–81 pp.
134. DiCarlo A, White N, Guo F, Garrett P, Litovitz T. Chronic electromagnetic field exposure decreases HSP70 levels and lowers cytoprotection. J Cell Biochem 2002;84:447–54.
135. Blank M. Overpowered, what science tells us about the dangers of cell phones and other Wi-Fi-age devices. New York: Seven Stories Press; 2014:28–9 pp.
136. Marino A. Assessing health risks of cell towers. In: Levitt BB, editor. Cell towers, wireless convenience? Or environmental hazard? Safe Goods/New Century, 2001. Bloomingtoin, IN: iUniverse, Inc; 2011:87–103 pp.
137. Lorenz EN. Deterministic nonperiodic flow. J Atmos Sci 1963;20: 130–41.
138. Lorenz EN. The predictability of hydrodynamic flow. Trans NY Acad Sci 1963;25:409–32.
139. Lorenz EN. Predictability. In: AAAS 139th meeting; 1972.
140. Peleg M. Biological phenomena are affected by aggregates of many radiofrequency photons. In: International conference on environmental indicators (ISEI), 11–14 Sept. 2011 in Haifa; 2011.
141. Kostoff RN, Lau CGY. Modified health effects of non-ionizing electromagnetic radiation combined with other agents reported in the biomedical literature. Chapter 4. In: Geddes CD, editor. Microwave effects on DNA and proteins. New York, NY, USA: Springer International Publishing; 2017.
142. Peleg M. Thermodynamic perspective on the interaction of radio frequency radiation with living tissue. Int J Biophys 2012; 2:1–6.
143. Panagopoulos DJ. Considering photons as spatially confined wave-packets. In: Reimer A, editor. Horizons in world physics. New York, NY, USA: Nova Science Publishers; 2015, vol 285.
144. Panagopoulos DJ. Man-made electromagnetic radiation is not quantized. In: Reimer A, editor. Horizons in world physics. New York, NY, USA: Nova Science Publishers, Inc.; 2018:296 p.
145. Panagopoulos D, Karabarbounis A. Comment on “Behavior of charged particles in a biological cell exposed to AC–DC electromagnetic fields” and on “Comparison between two models for interactions between electric and magnetic fields and proteins in cell membranes”. Environ Eng Sci 2011;28: 749–51.
146. Panagopoulos DJ, Margaritis LH. Theoretical considerations for the biological effects of electromagnetic fields. In: Stavroulakis P, editor. Biological effects of electromagnetic fields. New York, NY, USA: Springer Publisher; 2003:5–33 pp.
147. Tell RA, Kavet R. A survey of the urban radiofrequency (RF) environment. Radiat Protect Dosim 2014;162:499–507.
148. Sagar S, Dongus S, Schoeni A, Roser K, Eeftens M, Struchen B, et al. Radiofrequency electromagnetic field exposure in everyday microenvironments in Europe: a systematic literature review. J Expo Sci Environ Epidemiol 2017;28:147–60.
149. Sagar S, Adem SM, Struchen B, Loughran SP, Brunjes ME, Arangua L, et al. Comparison of radiofrequency electromagnetic field exposure levels in different everyday microenvironments in an international context. Environ Int 2018;114:297–306.
150. Gonzalez-Rubio J, Najera A, Arribas E. Comprehensive personal RFEMF exposure map and its potential use in epidemiological studies. Environ Res 2016;149:105112.
151. Tell RA, Mantiply ED. Population exposure to VHF and UHF broadcast radiation in the United States. Proc IEEE 1980;68: 6–12.
152. Moskowitz J. New study shows that cell phone towers are largest contributor to environmental radiofrequency radiation exposure; 2018. Available from: https://www.saferemr.com/2018/03/cell-phone-towers-are-largest.html.
153. Estenberg J, Augustsson T. Extensive frequency selective measurements of radiofrequency fields in outdoor environments performed with a novel mobile monitoring system. Bioelectromagnetics 2014;35:227–30.
154. Hardell L, Koppel T, Carlberg M, Ahonen M, Hedendahl L. Radiofrequency radiation at Stockholm Central Railway Station in Sweden and some medical aspects on public exposure to RF fields. Int J Oncol 2016;49:1315–24.
155. Hardell L, Carlberg M, Koppel T, Hedendahl L. High radiofrequency radiation at Stockholm old town: an exposimeter study including the royal Castle, Supreme Court, three major squares and the Swedish parliament. Mol Clin Oncol 2017;6:462–76.
156. Bolte JF, Eikelboom T. Personal radiofrequency electromagnetic field measurements in The Netherlands: exposure level and variability for everyday activities, times of day and types of area. Environ Int 2012;48:133–42.
157. Frei P, Mohler E, Neubauer G, Theis G, Bürgi A, Fröhlich J, et al. Temporal and spatial variability of personal exposure to radio frequency electromagnetic fields. Environ Res 2009;109: 779–85.
158. Joseph W, Frei P, Roösli M, Thuróczy G, Gajsek P, Trcek T, et al. Comparison of personal radio frequency electromagnetic field exposure in different urban areas across Europe. Environ Res 2010;110:658–63.

159. Markakis I, Samaras T. Radiofrequency exposure in Greek indoor environments. Health Phys 2013;104:293–301.
160. Rowley JT, Joyner KH. Comparative international analysis of radiofrequency exposure surveys of mobile communication radio base stations. J Expo Sci Environ Epidemiol 2012;22: 304–15.
161. Rowley JT, Joyner KH. Observations from national Italian fixed radiofrequency monitoring network. Bioelectromagnetics 2016; 37:136–9.
162. Urbinello D, Huss A, Beekhuizen J, Vermeulen R, Röösli M. Use of portable exposure meters for comparing mobile phone base station radiation in different types of areas in the cities of Basel and Amsterdam. Sci Total Environ 2014;468–469: 1028–33.
163. Viel JF, Cardis E, Moissonnier M, de Seze R, Hours M. Radiofrequency exposure in the French general population: band, time, location and activity variability. Environ Int 2009;35: 1150–4.
164. Viel JF, Clerc S, Barrera C, Rymzhanova R, Moissonnier M, Hours M, et al. Residential exposure to radiofrequency fields from mobile phone base stations, and broadcast transmitters: a population-based survey with personal meter. Occup Environ Med 2009;66:550–6.
165. Viel JF, Tiv M, Moissonnier M, Cardis E, Hours M. Variability of radiofrequency exposure across days of the week: a population-based study. Environ Res 2011;111:510–3.
166. Kasevich RS. Brief overview of the effects of electromagnetic fields on the environment. In: Levitt BB, editor. Cell towers, wireless convenience or environmental hazards? Proceedings of the "cell towers forum" state of the science/state of the law. Bloomington, IN: iUniverse, Inc.; 2011:170–5 pp.
167. Anglesio L, Benedetto A, Bonino A, Colla D, Martire F, Fusette S, et al. Population exposure to electro-magnetic fields generated by radio base stations: evaluation of the urban background by using provisional model and instrumental measurements. Radiat Protect Dosim 2001;97:355–8.
168. Hardell L, Carlberg M, Hedendahl LK. Radiofrequency radiation from nearby base stations gives high levels in an apartment in Stockholm, Sweden: a case report. Oncol Lett 2018;15: 7871–83.
169. Rinebold JM. State centralized siting of telecommunications facilities and cooperative efforts with Connecticut towns. In: Levitt BB, editor. Cell towers, wireless convenience? Or environmental hazard? Proceedings of the cell towers forum, state of the science/state of the law. Bloomington, IN: iUniverse, Inc.; 2001:129–41 pp.
170. Santini R, Santini P, Danze JM, Le Ruz P, Seigne M. Enquête sur la sante´ de riverains de stations relais de te´le´- phonie mobile: incidences de la distance et du sexe. Pathol Biol 2002;50: 369–73.
171. Manville AM II. Human impact on the black bear in Michigan's Lower Peninsula. Int Conf Bear Res Manag 1983;5:20–33.
172. Lohmann KJ. Sea turtles: navigating with magnetism. Curr Biol 2007;17:R102–4.
173. Barron DG, Brawn JD, Weatherhead PJ. Meta-analysis of transmitter effects on avian behaviour and ecology. Methods Ecol Evol 2010;1:180–7.
174. Albrecht K. Microchip-induced tumors in laboratory rodents and dogs: a review of the literature 1990–2006. IEEE Int Symp Technol Soc 2010;2010:337–49.
175. Blanchard KT, Barthel C, French JE, Holden HE, Moretz R, Pack FD, et al. Transponder-induced sarcoma in the heterozygous p53+/− mouse. Toxicol Pathol 1999;27:519–27.
176. Elcock LE, Stuart BP, Wahle BS, Hoss HE. Tumors in long-term rat studies associated with microchip animal identification devices. Exp Toxicol Pathol 2001;52:483–91.
177. Johnson K. Foreign-body tumorigenesis: sarcomas induced in mice by subcutaneously implanted transponders. Toxicol Pathol 1996;33:619.
178. Le Calvez S, Perron-Lepage M-F, Burnett R. Subcutaneous microchip-associated tumours in B6C3F1 mice: a retrospective study to attempt to determine their histogenesis. Exp Toxicol Pathol 2006;57:255–65.
179. Palmer TE, Nold J, Palazzolo M, Ryan T. Fibrosarcomas associated with passive integrated transponder implants. In: 16th international symposium of the society of toxicologic pathology. Toxicol Pathol 1998;26:165–76.
180. Tillmann T, Kamino K, Dasenbrock C, Ernst H, Kohler M, Moraweitz G, et al. Subcutaneous soft tissue tumours at the site of implanted microchips in mice. Exp Toxicol Pathol 1997;49: 197–200.
181. Vascellari M, Mutinelli F, Cossettini R, Altinier E. Liposarcoma at the site of an implanted microchip in a dog. Vet J 2004;168: 188–90.
182. Vascellari M, Mutinelli F. Fibrosarcoma with typical features of postinjection sarcoma at site of microchip implant in a dog: histologic and immunohistochemical study. Vet Pathol 2006; 43:545–8.
183. Paik MJ, Kim HS, Lee YS, Choi HD, Pack JK, Kim N, et al. Metabolomic study of urinary polyamines in rat exposed to 915 MHz radiofrequency identification signal. Amino Acids 2016;48: 213–7.
184. Ball DJ, Argentieri G, Krause R, Lipinski M, Robison RL, Stoll RE, et al. Evaluation of a microchip implant system used for animal identification in rats. Lab Anim Sci 1991;41:185–6.
185. Darney K, Giraudin A, Joseph R, Abadie P, Aupinel P, Decourtye A, et al. Effect of high-frequency radiations on survival of the honeybee (*Apis mellifera* L.). Apidologie 2015;47:703–10.
186. Murasugi E, Koie H, Okano M, Watanabe T, Asano R. Histological reactions to microchip implants in dogs. Vet Rec 2003;153: 328–30.
187. Rao GN, Edmondson J. Tissue reaction to an implantable identification device in mice. Toxicol Pathol 1990;18:412–6.
188. Raybuck DW, Larkin JL, Stoleson SH, Boves TJ. Mixed effects of geolocators on reproduction and survival of Cerulean Warblers, a canopy-dwelling, long-distance migrant. Condor 2017;119: 289–97.
189. Calvente I, Fernández MF, Pérez-Lobato R, Dávila-Arias C, Ocón O, Ramos R, et al. Outdoor characterization of radiofrequency electromagnetic fields in a Spanish birth cohort. Environ Res 2015;138:136–43.
190. Lahham A, Ayyad H. Personal exposure to radiofrequency electromagnetic fields among palestinian adults. Health Phys 2019;117:396–402.
191. Hamnerius Y, Uddmar T. Microwave exposure from mobile phones and base stations in Sweden. In: Proceedings of the international conference on cell tower sitting; 2000:52–63 pp.
192. Gryz K, Karpowicz J. Radiofrequency electromagnetic radiation exposure inside the metro tube infrastructure in Warszawa. Electromagn Biol Med 2015;34:265–73.

193. Joyner KH, Van Wyk MJ, Rowley JT. National surveys of radiofrequency field strengths from radio base stations in Africa. Radiat Protect Dosim 2014;158:251–62.
194. Sagar S, Struchen B, Finta V, Eeftens M, Röösli M. Use of portable exposimeters to monitor radiofrequency electromagnetic field exposure in the everyday environment. Environ Res 2016;150:289–98.
195. Stribbe M. Google blimps to bring wireless internet to Africa. Forbes 2013;15:757.
196. CBS News, Associated Press. U.S. tests spy blimps on Mexico border, August 22, 2012, 9:17 pm; 2012. Available from: http://www.cbsnews.com/news/us-tests-spy-blimps-on-mexico-border/.
197. NASA. National Aeronautics and Space Administration. Socioeconomic Data and Applications Center (SEDAC). The Last of the Wild Project, Version 2, 2005 (LWP-2): Global Human Footprint Dataset (Geographic), v2 (1995 – 2004); 2018. Available from: https://cmr.earthdata.nasa.gov/search/concepts/C179001808-SEDAC.html.
198. Center for Earth Science Information Network (CIESN). The last of the wild project, version 2, 2005 (LWP-2): global human footprint dataset (Geographic), v2 (1995 – 2004); 2018. https://doi.org/10.7927/H4M61H5F.
199. Macedo L, Salvador CH, Moschen N, Monjeau A. Atlantic forest mammals cannot find cellphone coverage. Biol Conserv 2018; 220:201–8.
200. Platt JR. No cell-phone reception? That's good news for Jaguars, a new study finds that the big cats and other endangered animals do best in places where there's no phone coverage. The Revelator; 2018. Available from: http://therevelator.org/phones-vs-jaguars/.
201. PEER. Public employees for environmental responsibility. Yellowstone backcountry blanketed with cell coverage, remotest corners now connected despite park promises of limited coverage; 2016. Available from: https://www.peer.org/news/news-releases/yellowstone-backcountry-blanketed-with-cell-coverage.html.
202. PEER. Public employees for environmental responsibility. Mount rainier wilderness slated for cell coverage, proposed cellular antennas in Paradise Visitor Center will wire wilderness; 2016. Available from: http://www.peer.org/news/news-releases/mount-rainier-wilderness-slated-for-cell-coverage.html.
203. Tobias J. The park service is selling out to telecom giants, with Trump's blessing, cell towers are infiltrating protected public lands across the west. High Country News; 2020. Available from: https://www.hcn.org/issues/52.3S/special-technology-the-park-service-is-selling-out-to-telecom-giants.
204. Ketcham C. Wiring the wilderness, the NP S is racing to expand cellphone service at parks nationwide. Do we really want a connected wild? Sierra; 2020. Available from: https://digital.sierramagazine.org/publication/?i=664414&article_id=3702685&view=articleBrowser.
205. NRDC. United keetoowah band of Cherokee Indians in okla. V. FCC, 933 F.3d 728 (D.C. Cir. 2019); 2019.
206. Meng YS, Lee YH, Ng BC. Study of propagation loss in forest environment. Prog Electromagn Res B 2009;17:117–33.
207. Kingsley D. Can't hear the conversation for the trees, News in Science, ABC Science Online; 2002. Available from: http://www.abc.net.au/science/articles/2002/06/12/578753.htm.
208. U.S. Federal Communications Commission. Federal Communications Commission Office of Engineering and Technology bulletin number 70 July, 1997, millimeter wave propagation: spectrum management implications. Federal Communications Commission Office of Engineering and Technology, New Technology Development Division; 1997. Available from: https://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet70/oet70a.pdf.
209. Hakusui SS Fixed wireless communications at 60 GHz unique oxygen absorption properties, RF globalnet, news; 2001. Available from: https://www.rfglobalnet.com/doc/fixed-wireless-communications-at-60ghz-unique-0001.
210. Ordance Survey 2018. Fifth generation mobile communications the effect of the built and natural environment on millimetric radio waves, Ordnance Survey 2018, for Department of Digital, Culture, Media and Sport February 2018 final report. Available from: http://bit.ly/Arbres_5G.
211. U.S. NWTT. Navy northwest training and testing (NWTT 2021); 2021. Available from: https://nwtteis.com/.
212. Jamail D. Navy plans electromagnetic war games over national park and forest in Washington state; 2014. Available from: http://www.truth-out.org/news/item/27339-navy-plans-electromagnetic-war-games-over-national-park-and-forest-in-washington-state.
213. Jamail D. Documents show navy's electromagnetic warfare training would harm humans and wildlife; 2014. Available from: http://www.truth-out.org/news/item/28009-documents-show-navy-s-electromagnetic-warfare-training-would-harm-humans-and-wildlife.
214. Vulnerable birds in the Pacific Flyway; 2021. Available form: https://www.audubon.org/climate/survivalbydegrees/flyway/pacific.
215. O'Rourke M. Lessons in stillness from one of the quietest places on earth, in the wilderness of Washington State's Hoh Rain Forest, a poet searches for the rare peace that true silence can offer. New York Times Magazine, travel issue; 2017. Available from: https://www.nytimes.com/2017/11/08/t-magazine/hoh-rain-forest-quietest-place.html.
216. Hempton G. One square inch, a sanctuary for silence at Olympic National Park; 2018. Available from: http://onesquareinch.org/.
217. National Parks Conservation Association (NPCA). New studies find navy growler jet noise around Olympic National Park harmful to humans and orcas; 2020. Available from: https://www.npca.org/articles/2776-new-studies-find-navy-growler-jet-noise-around-olympic-national-park.
218. U.S. Navy Northwest Training & Testing (NWTT). Update for: Olympic Coast National Marine Sanctuary (OCNMS) Advisory Council, January 20, 2017, John Mosher, U.S. pacific fleet, Dawn Grebner, Naval Undersea Warfare Center, Keyport, Jackie Queen, Naval Facilities Engineering Command NW; 2017. Available from: https://nmsolympiccoast.blob.core.windows.net/olympiccoast-prod/media/archive/involved/sac/nwtt_update-for-ocnms_advisory_council-20jan2017b.pdf.
219. U.S. Navy Northwest Training & Testing (NWTT). U.S. Navy Northwest Training and Testing (NWTT) 2017a. Public scoping summary report, Northwest Training and testing supplemental environmental impact statement/overseas environmental impact statement, Final 14 December 2017; 2017. Available

from: https://nwtteis.com/portals/nwtteis/files/public_information/NWTT_SEIS_OEIS-Scoping_Summary_Report.pdf.

220. U.S. Navy Northwest Training and Testing (NWTTEIS). Supplemental environmental impact statement/overseas environmental impact statement (EIS/OEIS); 2017. Available from: https://www.nwtteis.com/FAQs.

221. U.S. Navy Northwest Training and Testing (NWTTEIS). Draft environmental assessment for naval special operations training in Western Washington State, January 2018; 2018.

222. U.S. Navy Northwest Training and Testing; 2018. Available from: http://nwtteis.com/SearchResults.aspx?Search=Northwest+Electromagnetic+Radiation+Warfare+program.

223. U.S. Fish and Wildlife Service. Navy's Northwest training and testing activities offshore waters of Northern California, Oregon, and Washington, the inland waters of puget sound, and portions of the Olympic Peninsul; 2016. Available from: https://nwtteis.com/portals/nwtteis/files/2015-2016/NWTT_Final_USFWS_Biological_Opinion_7-21-2016.pdf.

224. U.S. Fish and Wildlife Service. Ibid 10.4.7.2.1.1., table 47, pp. 228 (Mosher, pers comm 2015; Navy 2014); 2016.

225. Sierra Club (North Olympic Group). Letter to: EA 18G EIS Project Manager, Naval Facilities Engineering Command (NAVFAC) Atlantic, Attn: Code EV21/SS, 6506 Hampton Blvd., Norfolk, VA 23508, Re: Draft EIS for EA-18G growler airfield operations at Naval Air Station (NAS) Whidbey Island; 2017. Available from: https://www.sierraclub.org/sites/www.sierraclub.org/files/sce/north-olympic-group/NOG%20letter%20re%20Growler%20Draft%20EIS%202-18-17.pdf.

226. Avian Power Line Interaction Committee (APLIC). Reducing avian collisions with power lines: the state of the art in 2012. Washington, DC: Edison Electric Institute and APLIC; 2012:159 p.

227. Washburn BE. Powerful tracking tools help reduce raptor conflicts. Wildl Prof 2015;9:34–7.

228. Jamail D. Emails reveal navy's intent to break law, threatening endangered wildlife. Truthout, Monday. Available from: http://www.truth-out.org/news/item/35954-exclusive-emails-reveal-navy-s-intent-to-break-law-threatening-endangered-wildlife.

229. Summary of the National Environmental Policy Act 42 U.S.C. §4321 et seq.; 1969. Available from: https://www.epa.gov/laws-regulations/summary-national-environmental-policy-act.

230. U.S. Navy Northwest Training and Testing. Final supplemental EIS/OEIS. NWTT supplemental EIS/OEIS/documents/2020, northwest training and testing final supplemental EIS/OEIS/final supplemental EIS/OEIS; 2020.

231. Save the Olympic Peninsula (SOP). Navy jets attempt evasive maneuver around NEPA; 2016. Available from: http://www.savetheolympicpeninsula.org/assets/update—navy-jets-attempt-evasive-maneuver.pdf.

232. Save the Olympic Peninsula (SOP). Once again – we must oppose military training in Washington State Parks; 2016. Available from: http://www.savetheolympicpeninsula.org/.

233. Sierra Club (North Olympic Group). Navy warfare training on the Olympic Peninsula; 2017. Available from: https://www.sierraclub.org/washington/north-olympic/navy-warfare-training-olympic-peninsula.

234. U.S. Navy Northwest Training and Testing. Final supplemental EIS/OEIS. NWTT supplemental EIS/OEIS/documents/2020, northwest training and testing final supplemental EIS/OEIS/final supplemental EIS/OEIS 3.6.2.3.2 through 3.6.2.3.3.2, pp. 3.6-9 through 3.6.7.1; 2020.

235. U.S. Fish and Wildlife Service. Navy's northwest training and testing activities offshore waters of northern California, Oregon, and Washington, the inland waters of Puget sound, and portions of the olympic Peninsula, 10.4.7.2.1.3., pp. 231; 2016. Available from: https://nwtteis.com/portals/nwtteis/files/2015-2016/NWTT_Final_USFWS_Biological_Opinion_7-21-2016.pdf.

236. U.S. Fish and Wildlife Service. Endangered species act – section 7 consultation, biological opinion, navy's northwest training and testing activities offshore waters of Northem California, Oregon, and Washington, the inland waters of puget sound, and portions of the Olympic Peninsula, U.S. Fish and Wildlife Service reference: 0lEWFW00-2015-F-0251-R00l; 2018. Available from: https://www.nwtteis.com/portals/nwtteis/files/2015-2016/U.S._Fish_and_Wildlife_Service_Reinitiated_Biological_Opinion_for_NWTT_Activities_%28Dec_2018%29.pdf.

237. Karam MA, Fung K, Antar YMM. Electromagnetic wave scattering from some vegetation samples. IEEE Trans Geosci Rem Sens 1988;26:799–807.

238. Karam MA, Fung AK, Amar F. Electromagnetic wave scattering from a forest or vegetation canopy: ongoing research at the University of Texas at Arlington. IEEE Antenn Propag Mag 1993; 35:18–26.

239. Pall ML. Electromagnetic fields act via activation of voltage-gated calcium channels to produce beneficial or adverse effects. J Cell Mol Med 2013;17:958–65.

240. Steiner I, Bruderer B. Anfangsorientierung und Heimkehrverhalten von Brieftauben unter dem Einfluss vonKurzwellen. J Ornithol 1999;140:34–41.

241. Bruderer B, Peter D, Steuri T. Behavior of migrating birds exposed to X-band radar and a brightlight beam. J Exp Biol 1999; 202:1015–22.

242. Wasserman FE, Dowd C, Schlinger BA, Byman D, Battista SP, Kunz TH. The effects of microwave radiation on avian dominance behavior. Bioelectronmagnetics 1984;5:331–9.

243. Grigor'ev I. Biological effects of mobile phone electromagnetic field on chick embryo (risk assessment using the mortality rate). Radiats Biol Radioecol 2003;43:541–3.

244. Xenos TD, Magras LN. Low power density RF radiation effects on experimental animal embryos and fetuses. In: Stavroulakis P, editor. Biological effects of electromagnetic fields. New York, NY, USA: Springer; 2003:579–602 pp.

245. Kuehne LM, Erbe C, Ashe E, Bogaard LT, Collins MS, Williams R. Above and below: military aircraft noise in air and under water at Whidbey Island, Washington. J Mar Sci Eng 2020;8:923.

246. NBC News. Smart refrigerators hacked to send out spam: report, Jan.18.2014/4:46 PM ET/Updated Jan.18.2014/5:20 PM ET. Available from: https://www.nbcnews.com/tech/internet/smart-refrigerators-hacked-send-out-spam-report-n11946.

247. U.S. Government Accountability Office (GAO). 5G deployment, FCC needs comprehensive strategic planning to guide its efforts, GAO-20-468: Published: Jun 12, 2020. Publicly released: Jun 29, 2020; 2020. Available from: https://www.gao.gov/products/GAO-20-468.

248. Levitt BB. Fiber broadband and small cells: an unholy municipal alliance, Counterpunch; 2019. Available from: https://www.

counterpunch.org/2019/05/13/fiber-broadband-and-small-cells-an-unholy-municipal-alliance/.

249. Pai A. Statement of Chairman Ajit Pai, Federal Communications Commission, hearing on oversight of the Federal Communications Commission, before the United States Committee on Commerce, Science and Transportation. Washington, D.C.; 2018.
250. Pai A. Remarks of FCC Chairman Ajit Pai to the American Council of Technology-Industry Advisory Council (ACT-IAC) Webinar on "5G: the future of digital connectivity and commerce"; 2020. Available from: https://www.fcc.gov/document/pai-act-iac-webinar-5g-future-digital-connectivity.
251. Dinucci M. 5G, the new track of the arms race. Global research; 2020. Available from: https://www.globalresearch.ca/5g-arms-race/5715138.
252. Statement of Jessica Rosenworcel, Commissioner, Federal Communications Commission. Hearing on oversight of the Federal Communications Commission before the United States Committee on Commerce, Science and Transportation. Washington, D.C.; 2018.
253. Leszczynski D. A class action against 5G deployment in Australia; 2018. Available from: https://www.emfacts.com/2018/07/a-class-action-against-5g-deployment-in-australia/.
254. Hardell L, Nyberg R. Comment: appeals that matter or not on a moratorium on the deployment of the fifth generation, 5G, for microwave radiation. Mol Clin Oncol 2020;12:247–57.
255. Seipel T. California: Gov. Jerry Brown vetoes bill easing permits on cell phone towers. The Mercury News; 2017. Available from: https://www.mercurynews.com/2017/10/16/california-gov-jerry-brown-vetoes-bill-easing-permits-on-cell-phone-towers/.
256. Erwin DN, Hurt WD. Assessment of possible hazards associated with applications of millimeter-wave systems. Aeromedical review USAF-SAM 2-81. USAF School of Aerospace Medicine, Aerospace Medical Division, Brooks AFB, TX 1981.
257. Gandhi O, Riazi A. Absorption of millimeter waves by human beings and its biological implications. IEEE Trans Microw Theor Tech 1986;34:228–35.
258. Marshall TG, Rumann Heil TJ. Electrosmog and autoimmune disease. Immunol Res 2017;65:129–35.
259. Joint Intermediate Force Capabilities Office, U.S Department of Defense Non-Lethal Weapons Program, Fact Sheets; 2020. Available from: https://jnlwp.defense.gov/Press-Room/Fact-Sheets/Article-View-Fact-sheets/Article/577989/active-denial-technology/.
260. Jauchem J. Bibliography of the Radio Frequency Radiation Branch, Directed Energy Bioeffects Division, Human Effectiveness Directorate, Air Force Research Laboratory: 1997–2003; 2004. Available from: https://www.researchgate.net/publication/235019072_Bibliography_of_the_Radio_Frequency_Radiation_Branch_Directed_Energy_Bioeffects_Division_Human_Effectiveness_Directorate_Air_Force_Research_Laboratory_1997-2003.
261. DARPA seeks to Improve Military Communications with Digital Phased-Arrays at Millimeter Wave, New program aims to create multi-beam, digital phased-array technology, operating at 18–50 GHz to enhance secure communications between military platforms. Available from: https://www.darpa.mil/news-events/2018-01-24.
262. Kenney JM, Ziskin M, Adair RA, Murray B, Farrer D, Marks L, et al. A narrative summary and independent assessment of the active denial system. The Human Effects Advisory Panel (HEAP), Penn State Applied Research Lab, February 11, 2008. Submitted in fulfillment of USMC contract no. M67854-05-D-5153-0007, Joint Non-Lethal Weapons Directorate, U.S. Department of Defense, pp. 23–26; 2008. Available from: https://jnlwp.defense.gov/Portals/50/Documents/Future_Non-Lethal_Weapons/HEAP.pdf.
263. Malyaso D. U.S. Air Force to spend $31 million for research 'bioeffects' of directed energy weapons, Defense Blog; 2019. Available from: https://defence-blog.com/news/u-s-air-force-to-spend-31million-for-research-bioeffects-of-directed-energy-weapons.html.
264. TASS. Russian News Agency Experts confirm technical readiness for study of 5G's effects on Moscow residents. The scheduled study must reveal, what level of radiation of various standards is safe for humans 8 Jul, 2020 10:58; 2020. Available from: https://tass.com/society/1176193.
265. Bushberg JT, Chou CK, Foster KR, Kavet R, Maxson DP, Tell RA, et al. IEEE committee on man and radiation—comar technical information statement: health and safety issues concerning exposure of the general public to electromagnetic energy from 5G wireless communications networks. Health Phys 2020;119: 236–46.
266. Bose JC. On the determination of the wavelength of electric radiation by a diffraction grating. Proc Roy Soc Lond 1897;60: 167–78.
267. Bose JC. On the change of conductivity of metallic particles under cyclic electromotive variation. In: Bose JC, editor. Originally presented to the British Association at Glasgow, September 1901, reproduced in collected physical papers. New York, N.Y.: Longmans, Green and Co.; 1927.
268. Emerson DT. The work of jagadis chandra bose: 100 years of millimeter-wave research. IEEE Trans Microw Theor Tech 1997; 45:2267–73.
269. Pakhomov AG, Akyel Y, Pakhomova ON, Stuck BE, Murphy MR. Current state and implications of research on biological effects of millimeter waves: a review of the literature. Bioelectromagnetics 1998;19:393–413.
270. Golant MB. Problem of the resonance action of coherent electromagnetic radiations of the millimetre wave range on living organisms. Biophysics 1989;34:370–82.
271. Golant MB. Resonance effect of coherent millimetre-band electromagnetic waves on living organisms. Biofizika 1989;34: 1004–14 (in Russian). English translation: Biophysics 1989;34: 1086–98.
272. Betzkii OV. Use of low-intensity electromagnetic millimeter waves in medicine. Millimetrovie Volni v Biologii i Meditcine 1992;1:5–12 (in Russian).
273. Betskii OV, Devyatkov ND, Kislov VV. Low intensity millimeter waves in medicine and biology. Crit Rev Biomed Eng 2000;28: 247–68.
274. Berezhinskii LL, Gridina NI, Dovbeshko GI, Lisitsa MP, Litvinov GS. Visualization of the effects of millimeter radiation on tremely high-frequency electromagnetic radiation on the function blood plasma. Biofizika 1993;38: 378–84 (in Russian).

275. Fesenko EE, Gluvstein AY. Changes in the state of water induced by radiofrequency electromagnetic fields. FEBS Lett 1995;367: 53–5.
276. Khizhnyak EP, Ziskin MC. Temperature oscillations in liquid media caused by continuous (nonmodulated) millimeter wavelength electromagnetic irradiation. Bioelectromagnetics 1996;17:223–9.
277. Kudryashova VA, Zavizion VA, Khurgin YV. Effects of stabilization and destruction of water structure by amino acids. In: Moscow, Russia: 10th Russian symposium "millimeter waves in medicine and biology" (Digest of papers). Moscow: IRE RAN; 1995:213–5 pp. (in Russian).
278. Litvinov GS, Gridina NY, Dovbeshko GI, Berezhinsky LI, Lisitsa MP. Millimeter wave effect on blood plasma solution. Electro-Magnetobiol 1994;13:167–74.
279. Zavizion VA, Kudriashova VA, Khurgin YI. Effect of alpha-amino acids on the interaction of millimeter-wave radiation with water. Millimetrovie Volni v Biologii i Meditcine 1994;3:46–52 (in Russian).
280. Ryakovskaya ML, Shtemler VM. Absorption of electromagnetic waves of millimeter range in biological preparations with a plane-layer structure. In: Devyatkov ND, editor. Effect of nonthermal action of millimeter radiation on biological subjects. Moscow: USSR Academy of Sciences; 1983:172–81 pp. (in Russian).
281. Pakhomov A, Murphy MR. A comprehensive review of the research on biological effects of pulsed radio frequency radiation in Russia and the Former Soviet Union. In: Lin J, editor. Advances in electromagnetic fields in living systems. Plenum: Kluwer Academic Press; 2000, vol 3:265–90 pp.
282. Yanenko OP, Peregudov SN, Fedotova IV, Golovchanska OD. Equipment and technologies of low intensity millimeter therapy; 2014. Number 59 103ISSN 621.317 (in Russian). Available from: https://cyberleninka.ru/article/n/equipment-and-technologies-of-low-intensity-millimeter-therapy.
283. Betzalel N, Feldman Y, Ishai B. The Modeling of the absorbance of sub-THz radiation by human skin. IEEE Trans Terahertz Sci Technol 2018;7:521–8.
284. Cosentino K, Beneduci A, Ramundo-Orlando A, Chidichimo G. The influence of millimeter waves on the physical properties of large and giant unilamellar vesicles. J Biol Phys 2013;39: 395–410.
285. Betzalel N, Ishai P, Feldman Y. The human skin as a sub-THz receiver – does 5G pose a danger to it or not? Environ Res 2018; 163:208–16.
286. Betskii OV, Lebedeva NN. Low-intensity millimeter waves in biology and medicine, access through; 2000. Available from: https://stopsmartmetersbc.com/wp-content/uploads/2020/07/Low-intensity-Millimeter-Waves-in-Biology-and-Medicine-by-O.V.-Betskii-and-N.N.-Lebedeva-Moscow-Russia-2000.pdf.
287. Thielens A, Bell D, Mortimore DB, Greco MK, Martens L, Joseph W. Exposure of insects to radio-frequency electromagnetic fields from 2 to 120 GHz. Sci Rep 2018;8:3924.
288. Thielens A, Greco MK, Verloock L, Martens L, Joseph W. Radio-frequency electromagnetic field exposure of western honey bees. Sci Rep 2020;10:461.
289. Frohlich H. The biological effects of microwaves and related questions. Adv Electron Electron Phys 1980;53:85–152.
290. Frohlich H, editor. Biological coherence and response to external stimuli. Berlin: Springer-Verlag; 1988:265 p.
291. Gandhi OP. Some basic properties of biological tissues for potential biomedical applications of millimeter-waves. J Microw Power 1983;18:295–304.
292. Grundler W. Biological effects of RF and MW energy at molecular and cellular level. In: Rindi A, Grandolfo M, Michaelson SM, editors. Biological effects and dosimetry of radiation. Radiofrequency and microwave energies. New York: Plenum Press; 1983:299–318 pp.
293. Postow E, Swicord ML. Modulated fields and "window" effects. In: Polk C, Postow E, editors. Handbook of biological effects of electromagnetic fields. Boca Raton, FL: CRC Press, Inc.; 1986: 425–60 pp.
294. Grundler W, Keilman F, Froehlich H. Resonant growth rate response of yeast cells irradiated by weak microwaves. Phys Lett 1977;62A:463–6.
295. Grundler W, Keilman F, Putterlik V, Strube D. Resonant-like dependence of yeast growth rate on microwave frequencies. Br J Canc 1982;45:206–8.
296. Grundler W, Jentzsch U, Keilmann F, Putterlik V. Resonant cellular effects of low intensity microwave. In: Froehlich H, editor. Biological coherence and response to external stimuli. Berlin: Springer-Verlag; 1988:65–85 pp.
297. Golant MB, Kuznetsov AP, Boszhanova TP. Mechanisms of synchronization of the yeast cell culture by the action of EHF radiation. Biofizika 1994;39:490–5 (in Russian).
298. Pakhomova ON, Pakhomov AG, Akyel Y. Effect of millimeter millimeter waves on UV-induced recombination and mutagenesis in yeast. Bioelectrochem Bioenerg 1997;43: 227–32.
299. Dardanoni L, Torregrossa MV, Zanforlin L. Millimeter wave effects on Candida albicans cells. J Bioelectr 1985;4:171–6.
300. Shestopalova NG, Makarenko BI, Golovina LN, Timoshenko YP, Baeva TI, Vinokurova LV, et al. Modification of synchronizing effect of millimeter waves on first mitoses by different temperature regimens of germination. In: Moscow, Russia: 10th Russian symposium "millimeter waves in medicine and biology" April, 1995 (Digest of papers). Moscow: IRE RAN; 1995: 236–7 pp. (in Russian).
301. Levina MZ, Veselago IA, Belaya TI, Gapochka LD, Mantrova GM, Yakovleva MN. Influence of low-intensity VHF irradiation on growth and development of protozoa cultures. In: Deyatkov ND, editor. Millimeter waves in medicine and biology. Moscow: Radioelectronica; 1989:189–95 pp. (in Russian).
302. Tambiev AK, Kirikova NN, Lapshin OM, Betzkii OV, Novskova TA, Nechaev VM, et al. The combined effect of exposure to EMF of millimeter and centimeter wavelength ranges on productivity of microalgae. In: Devyatkov ND, editor. Millimeter waves in medicine and biology. Moscow: Radioelectronica; 1989:183–8 pp. (in Russian).
303. Kremer F, Santo L, Poglitsh A, Koschnitzke C, Behrens H, Genzel L. The influence of low intensity millimetre waves on biological systems. In: Froehlich H, editor. Biological coherence and response to external stimuli. Berlin: Springer-Verlag; 1988: 86–101 pp.
304. Rojavin MA, Ziskin MC. Medical application of millimetre waves. Q J Med 1998;91:57–66.
305. Brovkovich VM, Kurilo NB, Barishpol'ts VL. Action of millimeter-range electromagnetic radiation on the Ca pump of sarcoplasmic reticulum. Radiobiologiia 1991;31:268–71 (in Russian).

306. Burachas G, Mascoliunas R. Suppression of nerve action potential under the effect of millimeter waves. In: Devyatkov ND, editor. Millimeter waves in medicine and biology. Moscow: Radioelectronica; 1989:168–75 pp. (in Russian).
307. Chernyakov GM, Korochkin VL, Babenko AP, Bigdai EV. Reactions of biological systems of various complexity to the action of low-level EHF radiation. In: Devyatkov ND, editor. Millimeter waves in medicine and biology. Moscow: Radioelectronica; 1989:141–67 pp. (in Russian).
308. Pakhomov AG, Prol HK, Mathur SP, Akyel Y, Campbell CBG. Search for frequency-specific effects of millimeter-wave radiation on isolated nerve function. Bioelectromagnetics 1997; 18:324–34.
309. Pakhomov AG, Prol HK, Mathur SP, Akyel Y, Campbell CBG. Frequency-specific effects of millimeter wavelength electromagnetic radiation in isolated nerve. Electro-Magnetobiol 1997;16:43–57.
310. Pakhomov AG, Prol HK, Mathur SP, Akye Y, Campbell CBG. Role of field intensity in the biological effectiveness of millimeter waves at a resonance frequency. Bioelectrochem Bioenerg 1997;43:27–33.
311. Bulgakova VG, Grushina VA, Orlova TL, Petrykina ZM, Polin AN, Noks PP, et al. Effect of millimeter-band radiation of nonthermal intensity on the sensitivity of *Staphylococcus* to various antibiotics. Biofizika 1996;41:1289–93 (in Russian).
312. Akoev GN, Avelev VD, Semen'kov PG. Perception of the low-level millimeter-range electromagnetic radiation by electroreceptors of the ray. Dokl Akad Nauk 1992;322:791–4 (in Russian).
313. Potekhina IL, Akoyev GN, Yenin LD, Oleyner VD. Effects of low-intensity electromagnetic radiation in the millimeter range on the cardio-vascular system of the white rat. Fiziol Zh 1992;78: 35–41 (in Russian).
314. Kholodov YA. Basic problems of electromagnetic biology. In: Markov M, Blank M, editors. Electromagnetic fields and biomembranes. Boston, MA: Springer; 1988:109–16 pp.
315. Markov M, Blank M, editors. Electromagnetic fields and biomembranes. Boston, MA: Springer-Verlag US; 1988.
316. Levedeva NN. Neurophysiological mechanisms of biological effects of peripheral action of low-intensity nonionizing electromagnetic fields in humans. In: Moscow, Russia: 10th Russian symposium "millimeter waves in medicine and biology" (Digest of papers). Moscow: IRE RAN; 1995:138–40 pp. (in Russian).
317. Kolbun ND, Lobarev VE. Bioinformation interactions: EMF-waves. Kibern Vychislitel'naya Tekhnika 1988;78:94–9.
318. Betskii OV. On the mechanisms of interaction of low-intensity millimeter waves with biological objects. Radiophys Quantum Electron 1994;37:16–22.
319. Betskii OV, Putvinskii AV. Biological action of low intensity millimeter band radiation. Izv Vyssh Uchebn Zaved Radioélektron 1986;29:4 (in Rusian).
320. Chukova YP. Dissipative functions of the processes of interaction of electromagnetic radiation with biological objects. Biophysics 1989;34:975–8.
321. Devytkov ND, Goland MB. Informational nature of the nonthermal and some of the energy effects of electromagnetic waves on a living organism. Pis'ma Zh Tekh Fiz 1982;8: 39–41.
322. Devytkov ND, Goland MB, Trager AC. Role of synchronization in the impact of weak electromagnetic signals in the millimeter wave range on living organisms. Biophysics 1983;28:953–4.
323. Golant MB, Poruchikov PV. Role of coherent waves in pattern recognition and the use of intracellular information. Pis'ma Zh Tekh Fiz 1989;15:67–70.
324. Golant MB, Rebrova TB. Similarities between living organisms and certain microwave devices. Izv Vyssh Uchebn Zaved Radioélektron 1986;29:10–19.
325. Ramundo-Orlando A. Effects of millimeter waves radiation on cell membrane – a brief review. J Infrared, Millim Terahertz Waves 2010;31:1400–11.
326. Simkó M, Mattsson MO. 5G wireless communication and health effects–a pragmatic review based on available studies regarding 6–100 GHz. Int J Environ Res Publ Health 2019;16: 3406.
327. Alekseev SL, Ziskin MC. Biological effects of millimeter and submillimeter waves. In: Greenebaum B, Barnes F, editors. Handbook of biological effects of electromagnetic fields, 4th ed. Boca Raton, FL: CRC Press; 2019, Chapter 6:179–242 pp.
328. Siegel PH, Pikov V. Impact of low intensity millimetre waves on cell functions. Electron Lett 2010;46:70–2.
329. Albanese RA. Is phased array radiation a separate category that requires safety testing? Unpublished article submitted to Air Force review, Sept. 2000.
330. Albanese R. Why would a medical doctor in Texas have a concern about the PAVE PAWS radar system on Cape Cod? Cape Cod Times, Letter to the editor, January 27, 2002.
331. Erdreich L, Gandhi OP, Lai H, Ziskin MC. Assessment of public health concerns associated with PAVE PAWS radar installations. Report prepared for the Massachusetts Department of Public Health; 1999. Available from: https://www.globalsecurity.org/space/library/report/1999/cape-cod_pavepaws-assess.htm.
332. Moulder J, Rockwell S. Critiquing unpublished theories. Radiat Res 2003;159:1–2.
333. Albanese R, Penn J, Medina R. Short-rise-time microwave pulse propagation through dispersive biological media. J Opt Soc Am A 1989;6:1441–6.
334. Albanese RA, Penn JW, Medina RL. An electromagnetic inverse problem in medical science. In: Corones JP, Nelson P, Kristenssoneditor G, editors. Invariant imbedding and inverse problems. Philadelphia: Society for Industrial and Applied Mathematics (SIAM); 1992:30–41 pp.
335. Albanese R, Penn J, Medina R. Ultrashort pulse response in nonlinear dispersive media. In: Bertoni HL, Carin L, Felsen LB, editors. Ultra-wideband, short-pulse electromagnetics. New York, NY, USA: Plenum Publishing; 1993:259–65 pp.
336. Albanese R, Blaschak J, Medina R, Penn J. Ultrashort electromagnetic signals: biophysical questions, safety issues, and medical opportunities. Aviat Space Environ Med 1994; 65(Suppl):A116–20.
337. Albanese RA, Medina RL, Penn JW. Mathematics, medicine, and microwaves. Inverse Probl 1994;10:995–1007.
338. Moten K, Durney CH, Stockham TG. Electromagnetic pulse propagation in dispersive planar dielectrics. Bioelectromagnetics 1989;10:35–49.
339. Oughstun KE, Sherman GC. Electromagnetic pulse propagation in causal dielectrics, Springer series on wave phenomena. Berlin-Heidelberg: Springer-Verlag; 1994, vol 16.

340. Hill K. Transitioning to a 5G world. RCR wireless; 2017. Available from: http://bit.ly/5Ghype.
341. National Research Council. An assessment of potential health effects from exposure to PAVE PAWS low-level phased-array radiofrequency energy. National Research Council; 2005:68–93 pp.
342. Blaschak JG, Franzen J. Precursor propagation in dispersive media from short-rise-time pulses at oblique incidence. J Opt Soc Am A 1995;12:1501–12.
343. Oughstun KE. Noninstantaneous, finite rise-time effects on the precursor field formation in linear dispersive pulse propagation. J Opt Soc Am A 1995;12:1715–29.
344. Oughstun KE. Dynamical evolution of the Brillouin precursor in the Rocard–Powles–Debye model dielectrics. IEEE Trans Antenn Propag 2005;53:1582–90.
345. Oughstun K. Electromagnetic and optical pulse propagation 1: temporal pulse dynamics in dispersive, attenuative media. New York, NY, USA: Springer International Publishing; 2006.
346. Palombini C, Oughstun K. Reflection and transmission of pulsed electromagnetic fields through multilayered biological media. In: Proceedings – 2011 international conference on electromagnetics in advanced applications, ICEAA’11; 2011.
347. Xu X, Chen P. A study on the possibility of applying precursor waves to penetration imaging. In: IEEE 2010 international conference on electromagnetics in advanced applications (ICEAA) – Sydney, Australia (2010.09.20–2010.09.24); 2010.
348. Sommerfeld A. Uber die fortpflanzung des lichtes in diesperdierenden medien. Ann Phys 1914;44:177–202. [English translation available in Brillouin, L., 1960: About the propagation of light in dispersive media. Wave Propagation and Group Velocity, Pure Appl Phys 1960;8:17–42].
349. Brillouin L. Uber die fortpflanzung des lichtes in diesperdierenden medien Ann Phys 1914;44:203–240. [English translation available in Brillouin L. About the propagation of light in dispersive media. Wave Propagation and Group Velocity, Pure Appl Phys 1960;8:43–83].
350. Plesko P, Palocz I. Experimental observation of the Sommerfeld and Brillouin precursors in the microwave domain. Phys Rev Lett 1969;22:1201–4.
351. Albanese RA. Wave propagation inverse problems in medicine and environmental health. In: Chavent G, Sacks P, Papanicolaou G, Symes WW, editors. Inverse problems in wave propagation. The IMA volumes in mathematics and its applications. New York, NY: Springer; 1997, vol 90:1–11 pp.
352. Albanese RA, Bell EL. Radiofrequency radiation and chemical reaction dynamics. In: Adey WR, Lawrence AF, editors. Nonlinear electrodynamics in biological systems. New York, NY, USA: Plenum Publishing; 1984:277–85 pp.
353. Albanese RA, Bell EL. Electromagmetic pulse distortion by a half-space. In: Abstracts of the seventh annual meeting of the bioelectromagnetics society; 1985:40 p.
354. Rogers W. Extension of the single pulse, contact stimulation strength duration curve down to 5 nanoseconds. Poster 116. Quebec City, Canada: Bioelectromagnetics Society; 2002.
355. D’Ambrosio R, Massa M, Scarfi R, Zeni O. Cytogentic damage in human lymphocytes following GMSK phase modulated microwave exposure. Bioelectromagnetics 2002;23:7–13.
356. Yamazaki S, Harata M, Ueno Y, Tsubouchi M, Konagaya K, Ogawa Y, et al. Propagation of THz irradiation energy through aqueous layers: demolition of actin filaments in living cells. Sci Rep 2020;10:9008.
357. Haas H. LiFi is a paradigm-shifting 5G technology. Rev Phys 2018;3:26–31.
358. Buck J. NASA laser communication system sets record with data transmissions to and from moon. NASA. Available from: http://www.nasa.gov/press/2013/october/nasa-laser-communication-system-sets-record-with-data-transmissions-to-and-from/#.UnayBpRAQcx.
359. Riebeek H. Catalog of earth satellite orbits, NASA earth observatory; 2009. Available from: https://earthobservatory.nasa.gov/Features/OrbitsCatalog.
360. U.S. Federal Communications Commission. Public notice: further guidance for broadcasters regarding radiofrequency radiation and the environment; 1986. Available from: https://docs.fcc.gov/public/attachments/DOC-8507A1.pdf.
361. O’Callaghan J. The FCC’s approval of SpaceX’s Starlink mega constellation may have been unlawful. Scienftific American Space; 2020. https://www.scientificamerican.com/article/the-fccs-approval-of-spacexs-starlink-mega-constellation-may-have-been-unlawful/.
362. Lehoucq R, Graner F. The costly collateral damage from Elon Musk’s Starlink satellite fleet, Phys.org; 2020. Available from: https://phys.org/news/2020-05-costly-collateral-elonmusk-starlink-satellite.html.
363. Cao S. SpaceX Starlink tracker: every satellite launched and how to see them in the sky. Observer 08/08/20 8:11 am; 2020. Available from: https://observer.com/2020/08/spacex-starlink-satellite-launch-tracker-how-to-see-in-sky/.
364. U.S. Federal Communications Commission (FCC). Public notice, Federal Communications Commission, 445 12th street S.W.Washington D.C. 20554, news media information 202-418-0500 internet: http://www.fcc.gov (or ftp.fcc.gov)TTY (202) 418-2555 Wednesday March 18, 2020 Report No. SES-02250 re: actions taken satellite communications services information; 2020. Available from: https://licensing.fcc.gov/ibfsweb/ib.page.FetchPN?report_key=2225961.
365. Zafar R. SpaceX wins FCC approval to test Starlink ground stations in 6 states, WCCFTech; 2020. Available from: https://wccftech.com/spacex-starlink-ground-stations-test/.
366. Shields T. Amazon’s kuiper satellite plan wins backing of FCC chair, bloomberg technology, July 10, 2020, 5:59 PM EDT Updated on July 10, 2020, 9:30 PM EDT; 2020. Available from: https://www.bloomberg.com/news/articles/2020-07-10/amazon-s-kuiper-satellite-plan-wins-backing-of-fcc-chairman.
367. U.S. Federal Communications Commission. International bureau FCC selected application listing BY file number report WR07 – wed aug 22 16:16:00 US/eastern 2018. File number = SATLOA2016111500118; 2018. Available from: https://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/reports/swr031b.hts?q_set=V_SITE_ANTENNA_FREQ.file_numberC/File+Number/%3D/SATLOA2016111500118&prepare=&column=V_SITE_ANTENNA_FREQ.file_numberC/File+Number&utm_content=bufferda647.
368. Erwin S. GAO flags concerns about procurement of DoD’s early warning satellites, Space News; 2020. Available from: https://spacenews.com/gao-flags-concerns-about-procurement-of-dods-early-warning-satellites/.
369. Erwin S. SATELLITES: on national security, the promise and perils of LEO constellations. Space News; 2020. Available from:

https://spacenews.com/the-promise-and-perils-of-leo-constellations/.

370. Wattles J. SATELLITES: SpaceX and ULA win military launch competition worth $653 million – and that's just the start. CNN Business, Updated 7:46 PM ET; 2020. Available from: https://www.cnn.com/2020/08/07/tech/spacex-ula-military-national-security-contract-scn/index.html.
371. Shepardson D. Key U.S. Senate republican places hold on FCC nomination over Ligado. Reuters U.S. July 28, 2020/3:48 PM; 2020. Available from: https://www.reuters.com/article/us-usa-telecom-wireless-idUSKCN24T2QO.
372. NRDC. Brief: Natural Resources Defense Council et al. as Amici Curiae in support of Petitioners, Envtl. Health Trust et al. v. FCC, D.C. Circuit Nos. 20–1025 20-1025, 20-1138 (August 5, 2020); 2020. Available from: https://www.nrdc.org/sites/default/files/amicus-brief-fcc-20200805.pdf.
373. Raghuram R, Bell TF, Helliwell RA, Katsufrakis JP. A quiet band produced by VLF transmitter signals in the magnetosphere. Geophys Res Lett 1977;4:199–202.
374. Robinson TR, Yeomanm TK, Dhillon RS. Environmental impact of high power density microwave beams on different atmospheric layers. Radio and Space Plasma Physics Group, Department of Physics and Astronomy, University of Leicester, Leicester LE1 7RH, UK. ESA contract number: 18156/04/NL/MV; 2004. Available from: http://www.esa.int/gsp/ACT/doc/ARI/ARI%20Study%20Report/ACT-RPT-NRG-ARI-04-9102-Environmental_impacts_of%20microwave_beams-Report.pdf.
375. Koh C. The benefits of 60 GHz unlicensed wireless communications. Comments filed at FCC; 2004. Available from: https://www.fcc.gov/file/14379/download.
376. Helliwell RA. Whistlers and related ionospheric phenomena. Mineola, N.Y.: Dover Publications; 1965.
377. Ryan K. The fault in our stars: challenging the FCC's treatment of commercial satellites as categorically excluded from review under the national environmental policy act; 2020. Available from: www.jetlaw.org/wp-content/uploads/2020/05/22.4-Ryan.pdf.
378. U.S. Code of Federal Regulations, Federal Register. § 1.1306 actions which are categorically excluded from environmental processing, updated 8/19/2020; 2020. Available from: https://ecfr.federalregister.gov/current/title-47/chapter-I/subchapter-A/part-1/subpart-I/section-1.1306.
379. Foust J. Senators ask GAO to review FCC oversight of satellite constellations, Space News; 2020. Available from: https://spacenews.com/senators-ask-gao-to-review-fcc-oversight-of-satellite-constellations/.

Supplementary Material: The online version of this article offers supplementary material (https://doi.org/10.1515/reveh-2021-0026).

Part 1, Supplement 1
Environmental EMF measurements from around the world

Locations of measurements	**Type of RFR**	**Level (μW/cm^2)**	**Reference**
Australia	870-1200 MHz	0.8	Henderson and Bangay (2006)
Australia and Belgium	In various public places	Australia : 0.15-4.97 (0.75-4.33 V/m) ; Belgium : 0.2-1.008 (0.90-1.95 V/m)	Bhatt et al. (2016)
Australia (Melbourne kindergartens)	88 MHz – 5.8 GHz	0.0017 (total all bands) (0.179 V/m)	Bhatt et al. (2017)
Belgium	FM, GSM900, GSM1800 and UMTS	0.07	Joseph et al. (2008)
Belgium, Switzerland, Slovania, Hungary, the Netherlands	Several fréquency bands	outdoor urban fields: 0.021-0.057	Joseph et al. (2010)
Brazil	Cell tower	0.04 - 40.78 (0.4-12.4 V/m)	Dode et al. (2011)
Denmark, the Netherlands, Slovenia, Switzerland, and Spain (children)	16 frequency bands including DECT, radio and TV, mobile phone,mobile phone base stations, and WiFi,	Median total field 0.00755 Outdoor : 0.0157-0.0171 Home/in school: 0.0033-0.00351	Birks et al. (2018)
France	12 bands: FM to mobile phone	0.6	Viel et al. (2009)
Germany (Cities of Bamberg and Hallstadt)	Mobile phone base station	0.001-1.69	Waldmann-Salsam et al. (2016)
Ghana	900-1800 MHz	0.001	Amoako et al. (2009)

Ghana	GSM 900, 1800 and UMTS 2100 (61.1-25.7 m from a basestation)	0.00717-0.0895	Deatanyah et al (2018)
Greece	62 primary and secondary schools in Athens (2- MHz – 3 GHz)	Average 0.049 (0.4292 v/m)	Aris et al. (2020)
Hungary	9 bands between 80-2200 MHz	0.025	Thuroczy et al. (2006)
India	10 MHz-8 GHz	1.148	Dhami (2012)
Korea	CDMA800 and CDMA1800	0.6	Kim et al. (2010)
Southern Spain	100 KHz – 6 GHz	0.0286	Calvente et al.(2015)
Sweden	30 MHz- 3 GHz	rural area 0.0016; urban area 0.027; city area 0.24	Estenberg and Augustsson (2014)
Sweden (Stockholm Central Railway Station)	88-5850 MHz	0.092 (median) 0.2817 -0.4891(mean total)	Hardell et al. (2016)
Sweden (Stockholm Old Town)	87-5850 MHz	0.0404 – 2.43	Hardell et al. (2017)
Switzerland	12 different bands from FM (88 MHz-108 MHz) to W-LAN (2.4-2.5 GHz)	0.013 (0.0014- 0.0881)	Frei et al. (2009)
Switzerland (Basel) and the Netherlands (Amsterdam)	Base stations	downtown: 0.024-0.0745 residential areas: 0.0021- 0.0445	Urbinello et al. (2014)
Switzerland, Ethiopia, Nepal, South Africa, Australia, USA	Public RFR emitting devices	Outdoor: 0.014-0.91 Public transport vehicles: 0.027-0.49	Sagar et al. (2018)
Turkey	GSM9 00 MHz	3	Firlarer et al. (2003)

USA (cities of Spokane, WA and Raleigh, NC)	VHF-FM-UHF-mobile phone	0.11- 0.00028	Tell and Kavet (2014)
West Bank-Palestine major cities, outdoor levels	FM and TV broadcasting stations and mobile phone base stations	Average 0.37 Maximum 3.86	Lahham and Hammash (2012)
West Bank-Palestine, City of Hebron, indoor levels	FM and TV broadcasting stations, mobile phone base stations, cordless phone (DECT) and WLAN	Average 0.08 Maximum 2.3	Lahham et al. (2015)
West Bank-Palestine	WLENS (Wi-Fi), 1 meter from access points, 75 MHz – 3 GHz	0.12 (0.001-1.9)	Lahham et al. (2017)

The above table shows a large variation in levels, ranging from 0.002 to 41 $\mu W/cm^2$ *(median =0.18* $\mu W/cm^2$*). The variation could most likely be due to the extent of deployment of wireless systems in different areas. Since each study measured only a section of the RF-spectrum, the total levels summing emissions in all parts of the spectrum are expected to be higher. These levels also are bound to increase with time given the constant deployment of new wireless communication devices and infrastructure. Some of the above are old measurements that probably are now higher as the wireless communication systems proliferated. For other relevant studies, readers should also read the review by Sagar et al. (2017)*

References

Amoako, J.K., Fletcher, J.J., Darko, E.O. Measurement and analysis of radiofrequency radiations from some mobile phone base stations in Ghana. Radiat Prot Dosimetry.135(4):256-260, 2009.

Aris, A., Yiannis, K., Vasiliki, S., Constantin, K., Charilaos, T., Kiki, T. 2020. RF-EMF Exposure Levels in Sensitive Land Use In Greece: Educational Units Census in the Municipality of Korydallos. Radiat. Prot. Dosimetry. doi: 10.1093/rpd/ncaa090. (online ahead of print).

Bhatt, C.R., Thielens, A., Billah, B., Redmayne, M., Abramson, M.J., Sim, M.R., Vermeulen, R., Martens, L., Joseph, W., Benke, G.. Assessment of personal exposure from radiofrequency-electromagnetic fields in Australia and Belgium using on-body calibrated exposimeters. Environ Res. 151:547-563, 2016.

Birks, L.E., Struchen, B., Eeftens, M., van Wel, L., Huss, A., Gajšek, P., Kheifets, L., Gallastegi, M., Dalmau-Bueno, A., Estarlich, M., Fernandez, M.F., Meder, I.K., Ferrero, A., Jiménez-Zabala, A., Torrent, M., Vrijkotte, T.G.M., Cardis, E., Olsen, J., Valič, B., Vermeulen, R., Vrijheid, M., Röösli, M., Guxens, M. Spatial and temporal variability of personal environmental exposure to radio frequency electromagnetic fields in children in Europe. Environ Int. 117:204-214, 2018.

Bhatt, C.R., Redmayne, M., Billah, B., Abramson, M.J., Benke, G. Radiofrequency-electromagnetic field exposures in kindergarten children. J Expo Sci Environ Epidemiol. 27:497-504, 2017.

Calvente I, Fernández MF, Pérez-Lobato R, Dávila-Arias C, Ocón O, Ramos R, Ríos-Arrabal S, Villalba-Moreno J, Núñez MI. Outdoor characterization of radio frequency electromagnetic fields in a Spanish birth cohort. Environ Resb 138:136-143, 2015.

Deatanyah, P., Amoako, J.K., Abavare, E.K.K., Menyeh, A. Analysis of electric field strength and power around selected mobile base stations. Radiat Prot Dosimetry. 179(4):383-390, 2018.

Dhami, A.K. Study of elelctromagnetic radiation pollution in an Indian city. Environ. Monit Assess 184: 8597-8512, 2012.

Dode, A.C., Leão, M.M., Tejo Fde, A., Gomes, A.C., Dode, D.C., Dode, M.C., Moreira, C.W., Condessa, V.A., Albinatti, C., Caiaffa, W.T. Mortality by neoplasia and cellular telephone base stations in the Belo Horizonte municipality, Minas Gerais state, Brazil. Sci Total Environ. 409(19):3649-3665, 2011.

Estenberg, J., Augustsson, T. Extensive frequency selective measurements of radiofrequency fields in outdoor environments performed with a novel mobile monitoring system. Bioelectromagnetics. 35(3):227-230, 2014.

Firlarer, A. Hamid, R., Cetintas, M., Karacadag, H., Gedik, A., Yogun, M., Celik, M. Measurement of electromagnetic radiation from GSM base stations. Proceedings of the IEEE International Symposium of Electromagnetic Compatibility, pp.1211-1214, 2003.

Frei, P., Mohler, E., Neubauer, G., Theis, G., Bürgi, A., Fröhlich, J., Braun-Fahrländer, C., Bolte, J., Egger, M., Röösli, M. Temporal and spatial variability of personal exposure to radio frequency electromagnetic fields. Environ Res. 109(6):779-785, 2009.

Hardell, L., Koppel, T., Carlberg, M., Ahonen, M., Hedendahl, L. Radiofrequency radiation at Stockholm Central Railway Station in Sweden and some medical aspects on public exposure to RF fields. Int J Oncol. 49(4):1315-1324, 2016.

Hardell, L., Carlberg, M., Koppel, T., Hedendahl, L. High radiofrequency radiation at Stockholm Old Town: An exposimeter study including the Royal Castle, Supreme Court, three major squares and the Swedish Parliament. Mol Clin Oncol 6(4):462-476, 2017.

Henderson, S.I., Bangay, M.J. Survey of RF exposure levels from mobile telephone base stations in Australia. Bioelectromagnetics. 27(1):73-76, 2006.

Joseph, W., Vermeeren, G., Verloock. L., Heredia, M.M., Martens, L. Characterization of personal RF electromagnetic field exposure and actual absorption for the general public. Health Phys. 95(3):317-330, 2008.

Joseph, W., Frei, P., Roösli, M., Thuróczy, G., Gajsek, P., Trcek, T., Bolte, J., Vermeeren, G., Mohler, E., Juhász, P., Finta, V., Martens, L. Comparison of personal radio frequency electromagnetic field exposure in different urban areas acromss Europe. Environ Res. 110(7):658-663, 2010.

Kim, B.C., Park, S.O. Evaluation of RF electromagnetic field exposure levels from cellular base stations in Korea. Bioelectromagnetics. 31:495-498, 2010.

Lahham, A., Hammash, A. Outdoor radiofrequency radiation levels in the West Bank-Palestine. Radiat Prot Dosimetry. 149(4):399-402, 2012.

Lahham, A., Sharabati, A., ALMasri, H. Public exposure from indoor radiofrequency radiation in the City of Hebron, West Bank-Palestine. Health Phys. 109(2):117-121, 2015.

Lahham, A., Sharabati, A., Al Masri, H.. Assessment of public exposure from WLANS in the West Bank Palestine. Radiat Prot Dosimetry 176(4):434-438, 2017.

Sagar, S., Adem, S.M., Struchen, B., Loughran, S.P., Brunjes, M.E., Arangua, L., Dalvie, M.A., Croft, R.J., Jerrett, M., Moskowitz, J.M., Kuo, T., Röösli, M. Comparison of radiofrequency electromagnetic field exposure levels in different everyday microenvironments in an international context. Environ Int. 114:297-306**,** 2018.

Tell RA, Kavet R. A survey of the urban radiofrequency (RF) environment. Radiat Prot Dosimetry. 162(4):499-507, 2014.

Thuróczy, G., Molnár, F., Szabó, J., Jánossy, G., Nagy, N., Kubinyi, G., Bakos J. 2006. Public exposure to RF from installed sources: site measurements and personal exposimetry. Proceedings of The European Conference on Antennas and Propagation: EuCAP 2006 (ESA SP-626). 6-10 November 2006, Nice, France. Editors: H. Lacoste & L. Ouwehand. Published on CDROM, p.51.

Urbinello D, Huss A, Beekhuizen J, Vermeulen R, Röösli M. Use of portable exposure meters for comparing mobile phone base station radiation in different types of areas in the cities of Basel and Amsterdam. Sci Total Environ. 468-469:1028-1033, 2014.

Viel, J.F., Cardis, E., Moissonnier, M., de Seze, R., Hours. M. Radiofrequency exposure in the French general population: band, time, location and activity variability. Environ Int. 35(8):1150-1154, 2009.

Waldman-Selsam, C., Balmori-de la Puente, A., Helmut Breunig, H., Balmori, A. Radiofrequency Radiation Injures Trees Around Mobile Phone Base Stations. Sci Total Environ 572:554-569, 2016.