Review Article

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Effects of non-ionizing electromagnetic fields on flora and fauna, Part 3. Exposure standards, public policy, laws, and future directions

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Abstract: Due to the continuous rising ambient levels of nonionizing electromagnetic fields (EMFs) used in modern societies—primarily from wireless technologies—that have now become a ubiquitous biologically active environmental pollutant, a new vision on how to regulate such exposures for non-human species at the ecosystem level is needed. Government standards adopted for human exposures are examined for applicability to wildlife. Existing environmental laws, such as the National Environmental Policy Act and the Migratory Bird Treaty Act in the U.S. and others used in Canada and throughout Europe, should be strengthened and enforced. New laws should be written to accommodate the ever-increasing EMF exposures. Radiofrequency radiation exposure standards that have been adopted by worldwide agencies and governments warrant more stringent controls given the new and unusual signaling characteristics used in 5G technology. No such standards take wildlife into consideration. Many species of flora and fauna, because of distinctive physiologies, have been found sensitive to exogenous EMF in ways that surpass human reactivity. Such exposures may now be capable of affecting endogenous bioelectric states in some species. Numerous studies across all frequencies and taxa indicate that low-level EMF exposures have numerous adverse effects, including on orientation, migration, food finding, reproduction, mating, nest and den building, territorial maintenance, defense, vitality, longevity, and survivorship. Cyto- and geno-toxic effects have long been observed. 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. A robust dialog regarding technology's high-impact role in the nascent field of electroecology needs to commence. Long-term chronic low-level EMF exposure standards should be set accordingly for wildlife, including, but not limited to, the redesign of wireless devices, as well as infrastructure, in order to reduce the rising ambient levels (explored in Part 1). Possible environmental approaches are discussed. This is Part 3 of a three-part series.

Keywords: aeroecology; electroecology; International Council on Non-ionizing Radiation Protection (ICNIRP); Migratory Bird Treaty Act (MBTA); National Environmental Policy Act (NEPA); non-ionizing electromagnetic fields (EMFs); radiofrequency radiation (RFR); rising ambient levels; U.S. Federal Communications Commission (FCC).

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Introduction

This is Part 3 and concludes a three-part series on electromagnetic field (EMF) effects to wildlife.

Part 1 focused on measurements of rising background levels in urban, suburban, rural, and deep forested areas as well as from satellites. Discussed were different physics models used to determine safety and their appropriateness to current exposures. The unusual signaling characteristics and unique potential biological effects from 5G were explored. The online edition of Part 1 contains a Supplement Table of measured global ambient levels.

Part 2 is an in-depth review of species extinctions, exceptional non-human magnetoreception capabilities, and other species' known reactions to anthropogenic EMF exposures as studied in laboratories and in the field. All animal kingdoms are included and clear vulnerabilities are seen. Part 2 contains four Supplement Tables of extensive low-level studies across all taxa, including ELF/RFR genotoxic effects.

Part 3 discusses current exposure standards, existing federal, and international laws that should be enforced but often are not, and concludes with a detailed discussion of aeroecology—the concept of defining air as habitat that would serve to protect many, though not all, vulnerable species today.

Government exposure standards

Extremely Low Frequency (ELF)

In the U.S., there are no federal government exposure standards for humans, much less wildlife, for the extremely low frequency (ELF) bands between 0 and 300 Hz. Within this range are the 50–60 Hz exposures common to powerlines and electric utility wiring that continue to rise due to our increasing energy demands, as well as electric utility grounding practices that use the Earth itself as the return neutral for excess current back to substations. Today in many regions, rather than run additional neutral lines (at significant expense) on utility poles along roadways to handle the extra harmonic load that all of our new electronic and wireless devices place on the lines, utilities siphon off excess voltage every few poles apart directly into the ground. Earth itself becomes the neutral line, sometimes with significant accumulations near substations that can elevate contact currents in nearby homes and outdoor environments, affecting pets and urban wildlife, as well as on underground metal gas pipelines that can form dangerous corrosion and hotspots [1]. In addition, new technologies like "wireless electricity"—called wireless power transfer (WPT)—to charge electric vehicles, batteries, computers, and chargers are coming on the market, creating novel ambient wireless and DC power exposures that we have never seen before, spanning from ELF through the 9 kHz to 40 GHz frequency bands. The technology is in nascent stages but involves transmission of power via RFR, most likely in the microwave bands at 2.45 GHz, to a special receiver called a rectenna that then converts it back to DC power for use in an ELF ambient capacity. The goal is to get rid of wires. This is a completely new exposure to which many species of flora and fauna are sensitive (see Part 2). Such industrial-scale grounding practices and wireless ELF/RFR have never been studied as environmental factors for air, land-based, or underground wildlife. This includes potential damage to flora with vulnerable root systems in the ground while their primary growth is above ground level (AGL), making flora susceptible to both ELF and radiofrequency radiation (RFR) exposures. Standards-setting groups may soon turn attention to ELF in light of WPT that is coming on the market with virtually no environmental review.

The U.S. Federal Communications Commission

In the U.S., the Federal Communications Commission (U.S. FCC) has jurisdiction over the licensing of electromagnetic spectrum use between 100 kilohertz (kHz) and 100 gigahertz (GHz), which includes cable TV/Internet, amateur radio, AM/FM commercial broadcast stations, wireless cellular facilities, satellite communications, and all other communications devices/services (See Figure 1). There are adopted and enforceable exposure standards in the radiofrequency bands between 300 kHz and 100 GHz under FCC—a non-health agency that relies on other agencies and outside expert groups for advice regarding human exposures ([2, 3], and see Part 1). FCC's 1997 standards were reviewed and reaffirmed in 2020 with minimal changes [4].

The model for the FCC standards are human-centric, based on short-term, acute high-intensity exposures to RFR that are capable of heating tissue the way a microwave oven cooks food. Thermal heating effects were well-quantified decades ago and are reasonably easy to regulate while allowing technology to flourish. It is the ubiquitous lower intensity exposures that are problematic and unregulated (see Part 2, Supplement 3 for effects at very low intensity exposures).

It is important to understand that the FCC standards (and other similar models) are exposure limits, not emissions allowances from generating sources although the two are intricately linked. As such, the standards are distance related with accessibility to a generating source being the most important factor, and they are relevant only to locations that are accessible to workers and/or members of the public [2, 5, 6]. This means that despite safety factors built in to such standards, ambient levels are largely unregulated outside of built environments.

However, while standards by any group are derived with only humans in mind, all measurement factors are potentially relevant metrics to species in the wild. Thus the large body of research intended to help set exposure limits for humans are germane to determining new standards to protect wildlife, at least in some very broad ways. But in regulating for wildlife, factors involving rising ambient levels (see Part 1) must include both exposure <u>and</u> emission considerations, due to the increased sensitivity to EMF/RFR of many species (see Part 2) based on taxonomy, size, physiology, habitat, magnetoreception, seasonal

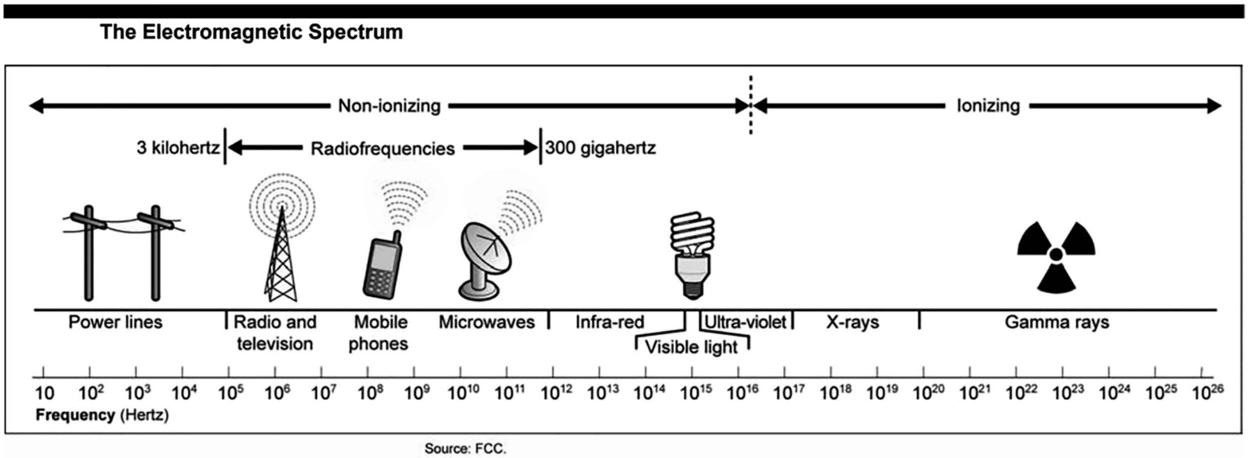

Figure 1: Illustration shows FCC area of regulatory responsibility between 100 kilohertz (kHz) up to the far microwave bands in the non-ionizing section of the spectrum. The frequency range for FCC limits cover from 300 kHz to 100 GHz. ([5] p. 3).

migration, and many other factors. Many airborne species, for example, have the ability to reach close proximities to antennas mounted on towers or buildings and routinely reach areas with detrimental levels of RFR even at some distance from transmitters. And several bird species fly at altitudes high enough to experience exposures from satellite systems that humans would never encounter. In essence, other species can experience both near-and-far-field exposures that humans rarely, if ever, experience and likely move in and out of such fields on a routine and/or seasonal basis.

Below is information on how governments regulate this subject regarding human exposures that point to possibilities for wildlife protection.

The U.S. FCC exposure standards are a two-tiered model based on recommendations from key regulatory agencies and two expert organizations: the National Council on Radiation Protection and Measurements (NCRP) report in 1986 [7, 8] and a subcommittee recommendation from 1992 to the American National Standards Institute (ANSI) by the International Electronics and Electrical Engineers (IEEE; [9]). The NCRP is a non-profit corporation chartered by the U.S. Congress to develop information and recommendations across many public and private sectors on radiation protection. The ANSI is a non-profit, privately funded, membership organization that coordinates the development of voluntary U.S. national standards used across all industry sectors. The IEEE is a non-profit, privately funded, technical, and professional/industry group that widely represents the technology sector with a membership of over 300,000 engineers and scientists worldwide; they have almost no biologists or members with medical backgrounds. ANSI, IEEE, and FCC are not health or environment-related entities, yet they play pivotal roles in non-ionizing radiation exposure regulation. NCRP does include human health expertise on their review panels. These various groups issue exposure guidelines. Once a government entity with enabling authority adopts such guidelines, they become enforceable and the government entity can require the private sector to abide by them as well as impose fines when they transgress. The FCC was given authority over RFR exposure standards adoption and enforcement by The Telecommunications (TCA) Act of 1996 [10].

At the impetus of the U.S. Environmental Protection Agency (U.S. EPA), the multi-agency Radiofrequency Interagency Working Group (RFIAWG) was formed in the 1990s. EPA, which has primacy over environmental radiation effects, was specifically defunded for non-ionizing radiation research and oversight in 1996 [11] just as the TCA was coming into effect. In lieu of EPA writing its own RFR exposure standards at the time—something they were poised to do and took criticism for not completing—EPA instead recommended a two-tiered exposure standard (see below) be adopted at FCC taken from recommendations by both NCRP and ANSI/IEEE, which FCC did in 1996. Subsequent to that, the RFIAWG also sent a letter in 1999 to the IEEE committee responsible for developing RF standards that listed 14 major topics and/or areas of concern related to any future revision of the IEEE standard [12]. Those concerns have yet to be addressed. The RFIAWG was comprised of key bioelectromagnetics scientists from seven or more U.S. federal regulatory agencies, representing health, the environment, and professional exposures (One of the authors of this paper was on RFIAWG representing the U.S. Fish and Wildlife Service). Although RFIAWG still exists on paper, it rarely meets, if at all, and is no longer the analytical advisory authority it once was to FCC. Consequently FCC regulates and issues rule-makings in an environmental vacuum, other than minimal comments provided by the Food and Drug Administration (U.S. FDA) which advises on devices like cell phones over which it has authority.

FCC is often now seen as an agency that is captured by the industries it is supposed to regulate [13] and because of cutbacks at key advisory agencies like EPA, FCC lacks the wider expertise upon which it relies to conduct thorough assessments regarding exposure safety [11].

What today's exposure standards measure

Most of the current guidelines used in Western countries are based on the specific absorption rate (SAR)—the rate of energy absorbed per unit mass of biological tissue with units expressed in watts per kilogram (W/kg) or milliwatts per kilogram (mW/kg) of tissue. Harmful effects from which the SAR was originally derived were based upon relatively few animal studies in the 1980s [14, 15] in which behavioral disruption was observed at approximately 4 W/kg when test animal body temperatures rose by about 1°C. Safety factors were built in to allow for unknown/unidentified effects and are reflected in the allowances noted below, but it is important to know that these additional margins are purely hypothetical. SARs are also studied on fluid-filled phantom laboratory models in the shape of human body parts, as well as cadavers which can never reflect the complexities of whole living electrodynamic organisms. SARs are extremely difficult, if not impossible, to measure in living models.

The FCC standards divide exposure allowances (based on the baseline or 4 W/kg) into two tiers legally defined as:

- **Occupational/controlled limits based on ANSI/IEEE:** Applies when people are exposed due to employment, provided they are fully aware of exposures and can exercise control over them. SAR is 0.4 W/kg, reflecting a safety factor of 10.
- **General population/uncontrolled limits based on NCRP:** Applies to when the general public may be exposed, or when people who are exposed as a consequence of employment may not be fully aware of potential exposure, or cannot exercise control over the exposure. SAR is 0.08 W/kg, reflecting a safety factor of 50.
- Limits are different for cell phone exposures when partial body exposure would be experienced and is derived by complicated methods of scaling from the whole body exposure. The SAR for partial body exposure is 1.6 W/kg measured over 1.0 g cube of tissue—a limit that all cell phones must meet in the U.S., and which is stricter than what is used in Europe as recommended by the ICNIRP guidelines (see below) at 2.0 W/kg averaged over 10 g of tissue. SAR evaluation continues to be required as the only acceptable compliance metric for portable devices below 6 GHz.
- In addition, there are whole-body SAR limits at 0.08 W/kg related to various factors including size, shape, and orientation toward a generating source, among other things. There are also higher SAR allowances for the body's extremities defined as hands, wrists, feet, and ankles, where the limit is 4 W/kg as averaged over any 10 g of tissue and where some peak allowances can be up to 8 W/kg over 1 g of tissue (it is assumed that extremities can absorb more energy without tissue heating [the ear—or pinna—was included as an extremity in 2013 – see discussion below]). There are also resonant SAR peaks for humans (maximum absorption rates) reflected in the illustration below. For whole-body human irradiation of a 6′ male, peak resonant SARs are reached in the bands between 70 and 100 Megahertz (MHz)—the middle of the FM radio band, where exposures are therefore most stringent (see Figure 2).

The frequency range for FCC limits covers from 300 kHz to 100 GHz and is dependent on frequency as defined in maximum permissible exposures (MPE). MPE's are given in terms of power density—milliwatts per centimeter squared (mW/cm^2)—or in field strength as volts per meter (V/m) or amperes per meter (A/m). Often far-field exposures from infrastructure are given in mW/cm^2 and MPE. (For a table of FCC MPE limits for occupational and general populations see reference [5], p. 15).

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) compared to the FCC

Countries throughout Europe and Canada have adopted standards based on recommendations by The International Commission on Non-Ionizing Radiation Protection (ICNIRP), a self-selecting group chartered in Germany in 1992 that functions as a collaborating non-state entity with the World Health Organization [16– 18]. ICNIRP is a

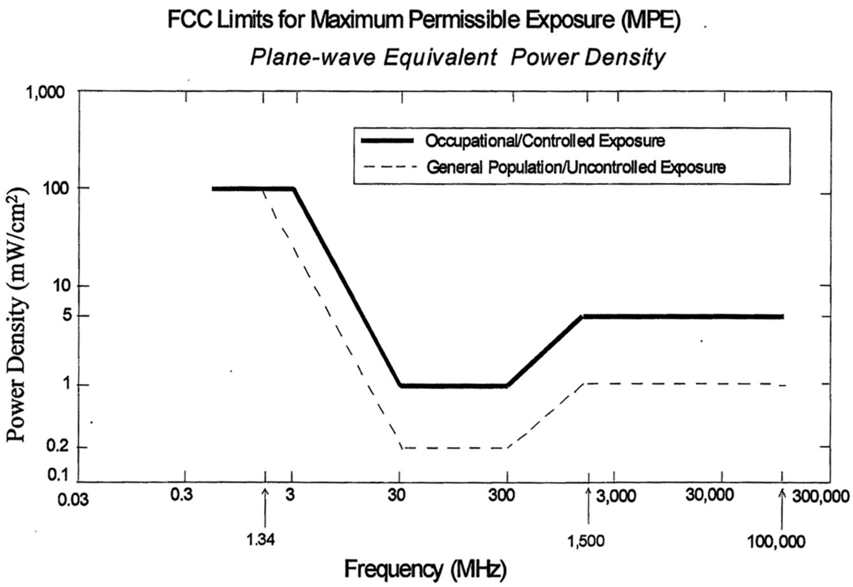

Figure 2: Worker limit is the solid line; general public is the dotted line.
Note that the strictest limit is in the 30–300 MHz range where human whole body resonance occurs. Standards-setting organizations have all made limits strictest in that region. Also note that higher limits are allowed on both sides of that area ([2] p. 69).

relatively new entity in standards setting, given that the ANSI-IEEE basic thermal exposure framework was first delineated and published in 1968 (at higher allowances) and the U.S. NCRP's basic reports on RF were published in 1986 and 1993 ([7, 8], respectively).

The FCC standards remain more stringent than ICNIRP's although in 2020 ICNIRP published an update of their 1998 allowances and adopted a few of FCC's measurements. Both remain two-tiered, human-centric, thermal-based models. ICNIRP differs in some exposure levels and averaging times, as well as allowances in some lower as well as upper frequency ranges that are more lenient than FCC. There is variation between countries that have adopted other standards, i.e., Italy and Switzerland use standards far below FCC and ICNIRP (see below).

By way of comparison: For power density (MPE) 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 and uncontrolled environments, FCC SAR levels require hand-held devices to be at or below 1.6 W/kg averaged over 1.0 g cube of tissue. For whole body exposures in uncontrolled environments, the limit is 0.08 W/kg. Canada, which previously had used the ICNIRP standard, now uses the FCC's 1.6 W/kg averaged over any 1.0 g of tissue and for whole body exposures, the limit is 0.08 W/kg. The peak spatially-averaged SAR in the limbs, averaged over any 10 g of tissue, is 4 W/kg. In European countries and elsewhere where the ICNIRP standard is used, the SAR limit for hand-held devices is higher than FCC at 2.0 W/kg averaged over 10 g cube tissue mass (than measurement, which changed in 2020, used to be over any contiguous tissue). Whole body exposure limits are the same at 0.08 W/kg but until recently were averaged differently: in the FCC standards they are averaged over 30 min; ICNIRP used to be averaged over 6 min but has now gone to 30 min for whole body exposures too [19]. ICNIRP's local body-area SARs are still averaged over 6 min.

The 2020 ICNIRP revision made some other critical changes that many find troubling (see below). Hardell et al. [20] published a recent thorough review and analysis of why these standards are not as protective of public health as many assume.

Longstanding criticism of FCC and ICNIRP standards

The longstanding primary criticism of both the FCC and ICNIRP standards is that they are based on short-term acute exposures for tissue heating—unlike today's more realistic long-term chronic low-level exposures—and that the safety factors of 10 and 50 below that acute heating threshold are purely suppositional [21]. There are other flaws with how these standards are written, for instance the effect of time averaging diminishes the biological significance of peak intensity short-term exposures. And because real-life exposures can be quite organ-specific, such as a cell phone held against the head or carried in a pocket, partial body exposure guidelines for specific organs may not be accurate, especially after the FCC ruled in 2013 that the human ear (pinna) can be classified as an appendage like arms or legs [22, 23], thereby allowing cell phones to transmit at higher levels with higher SAR limits.

This reclassification only changes exposures to the ear. FCC standards are still 1.6 W/kg as averaged over 1 g of tissue, except for extremities where the limit is 4 W/kg as averaged over 10 g of tissue (For occupational exposures, the localized SAR limit is 8 W/kg as averaged over 1 g of tissue, except for within the extremities where it is limited to 20 W/kg as averaged over 10 g of tissue). The ear now fits that higher allowance even though the auricle is simply not an 'extremity.' The auricle is histologically very different from arms or legs and lacks bone, tendon, and skeletal muscle. It is also very close to the human brain and eyes. In addition auricle nerves are innervated by the vagus nerve which in turn innervates many other vital organs in the body, including the heart, GI-tract, and reproductive organs. The higher allowance may also affect the eyes as many now text and look directly into a cell phone screen. This entire new classification should be reconsidered. The eye is a highly conductive aqueous saline organ—the exact opposite of cartilage. The reclassification is inviting adverse effects to the ear, the brain, the eyes, and potentially other systems in the body [23]. It also exponentially increases ambient RFR levels with the number of active cell phones in operation at any given location. Health concerns over human eyes directly translate to species with eye structures similar to humans which includes most mammals. But in other species, effects are potentially more dire. Many insect species, for instance, have compound eye structures with sometimes thousands of lenses in addition to which insects do not dissipate heat efficiently. Their smaller size also makes them a resonant match with RFR's higher frequencies.

Given the scale of human cell phone use today, that technology's contribution alone to ambient levels is not insignificant (see Part 1). Yet people rarely understand that their cell phone may cause downstream effects to other species. Raising the power density output of cell phones may be an environmental factor in and of itself. In fact many of the fundamental criticisms of the human exposure standards may have consequences at the ecosystem level to wildlife species (see Part 2 and below).

In addition, no current exposure standards at FCC or ICNIRP take into consideration signal modulation, wave form, or cumulative exposures from multiple low-power devices transmitting simultaneously—all biologically important factors that have been found in numerous studies to be independent of frequency alone (see Parts 1 and 2). And both FCC and ICNIRP categorically exclude whole classes of low-power devices from review if they adhere to a certain transmission level around 1 mW effective radiated power (ERP).

In other words, there are multiple problems and significant deficits with the most widely adopted exposure standards as originally conceived, formulated, written, and defended. Both major entities have recently reinforced and justified their exposure parameters despite decades of recent research pointing to adverse effects from exposures far below heating thresholds. Both FCC and ICNIRP are actually dosimetry-based models—meaning a defined minimum exposure that will allow technology to function without causing gross short-term adverse heating effects—rather than true biological models based on thresholds where effects are seen [12].

Today a growing number of people, domestic pets, and urban and suburban wildlife are exposed to 24 h EMFs from individual devices, products, and infrastructure [21, 24–27]. Popular wireless devices such as baby monitors, smart grid/meters, home and industrial appliances, WiFi routers, remote controls, security systems, personal "assistants" like Amazon's Alexa and Apple's Siri, and some wireless laptop computers fall at, or below, the power density level of 1 mW ERP which qualifies them for categorical exclusion (CE, or CatEx) from licensing review. This can include CatEx for small cell infrastructure too but there is complex overlap in some situations.

There is a distinction between "no license required" for low-power individual consumer devices vs. "no environmental review pursuant to a CatEx" for low power infrastructure. Small cell networks do require FCC licensing because they use the spectrum, even though individual antennas can be categorically excluded as low-powered. And because issuing a license is a major federal action, NEPA should apply, even though under some circumstances, a CatEx can satisfy NEPA compliance—see below. Today, FCC CatExs include most consumer wireless products and the infrastructure for hundreds of thousands of individual 4G and 5G small cells. Exclusion criteria are based on such factors as type of service, antenna height, and operating power. CatExs are not exclusions from compliance itself, but rather exclusions from performing routine evaluations to demonstrate such compliance and therein lay problems because no one is monitoring. Qualifying for CatEx is based on manufacturer's declarations. According to FCC OET Bulletin 65 (2 p. 12), "… the exclusion itself from performing routine evaluation will be a sufficient basis for assuming compliance, unless an applicant or licensee is otherwise notified by the FCC or has reason to believe that the excluded transmitter or facility encompasses exceptional characteristics that could cause non-compliance …" In other words, much of this semi-regulated area is based on the honor system.

CatEx does not mean that significant exposures are unrealistic or unlikely, especially from cumulative exposures from many devices working simultaneously as is the case in most homes and workplaces today. Although infrastructure is the dominant contributor to outdoor pollution (see Part 1), cell phones and some domestic WiFi systems can be significant contributors to ambient exposures in indoor as well as outdoor environments at levels known to affect wildlife (see Part 2, Supplement 3). What are widely thought to be local indoor transmitters such as personal WiFi and home signal boosters, can and do penetrate walls to become outdoor exposures too. Every new application, though functioning within its own categorically excluded parameter, adds that much more to the aggregate, in essence creating a synergistic effect with the sum of exposures being greater than the individual effects of each component part. Although aggregate RFR levels are not supposed to exceed the FCC or ICNIRP regulations, no regulatory entity today measures, enforces, or attempts to mitigate for this [23] unless complaints are filed over interference issues with other systems. Each CatEx exists within its own technical realm, considered safe if kept under 1 mW ERP. Most such excluded devices and/or networks have considerable overlap, creating multiple exposures, and possible elevated effects. This is not a realistic, scientifically sound, or safe way to determine actual exposures to humans, domestic animals, or wildlife from aggregate, ambient radiation.

5G: changes at FCC and ICNIRP

5G is poised to bring radical changes to the ambient landscape from individual devices and especially infrastructure exposures, yet the major standards-setting groups have recently reinforced and justified their existing exposure allowances [3, 18, 19]. They continue to adhere to acute dosimetry-based frameworks rather than true biological models based on more sensitive thresholds where effects are seen. Plus, a most urgent area in need of clarification concerns how traditional standards have been written from the outset, which may, in fact, be based on a fundamental theoretical flaw. We may not even be using the correct physics model in today's standards setting (see Part 1) in light of actual exposures. The entire justification for adhering to thermoregulatory models rests on the classic physics theory of non-ionizing radiation not having enough energy to knock electrons off cellular orbits and thereby cause DNA damage. This may not be the most accurate model regarding biological reactions/interactions with low-level energy found in current exposures [28–32]. The classic theory is based on a mathematical calculation best suited to ionizing radiation and a narrow definition of a one-cell, one-photon concept whereas today's exposures are many simultaneous and often-overlapping streaming photons arriving at multiple cells from multiple angles at the same time in what behave more like photon wave "packets" rather than single photons [33–39] Our entire regulatory concept needs further attention if we are to truly understand and trust where we are headed with 5G's new technology.

To better accommodate 5G's buildout, all exposure limits at FCC and INCIRP may soon become more lenient. FCC has opened a new docket (Docket #19-226) to target the need for different regulations for 5G [40], even as they have stated their current regulations are adequate for 5G exposures [3]. The new FCC docket covers a wider frequency range from 3 kHz to 3 THz for permissible human exposures and has allocated certain applications in the millimeter (MMW) bands from 57.05 to 64 GHz for unlicensed use, meaning CatEx for some devices and infrastructure. FCC is also seeking comments on applying localized exposure limits above 6 GHz in parallel to the localized exposure limits already established below 6 GHz, as well as specifying new conditions and methods for averaging RFR for both time and exposure area. They are also seeking comment on new issues raised by WPT devices [3].

There have been numerous comments submitted to FCC regarding Docket 19-226 by citizens, organizations, and professional groups like the American Public Power Association (APPA) urging FCC not to further expand unlicensed operations in the 6 GHz bandwidth due to possible interference with present licensed systems, among many other issues. Numerous comments also center on health/environmental concerns [41].

There has been significant discussion at FCC and ICNIRP about changing SAR exposure categories that are now used for cell phones and other mobile/portable devices to a mW/cm^2 power density exposure measurement (MPE) for devices above 6 GHz, which 5G phones will be. FCC states that for portable devices operating at frequencies above 6 GHz, 'special frequency' considerations are necessary [2]. The localized SAR criteria used by the FCC only apply at operating frequencies between 100 kHz and 6 GHz. For portable devices that operate above 6 GHz (e.g., 5G millimeter-wave devices) they say that localized SAR is not an appropriate means for evaluating exposure; that at the higher frequencies, exposure from portable devices should be evaluated in terms of power density MPE limits instead of SAR, adding that power density values can be either calculated or measured, as appropriate, at a minimum distance of 5 cm from the radiator of a portable device to show compliance with FCC standards (2 p. 43–44). They do not elaborate on their reasons but it may have to do with the assumption that MMW do not penetrate skin deeply, which has been proven false (see Part 1 and below).

With 5G in mind, ICNIRP (2020) also addressed the subject of special "transition frequency" [19]—the frequency at which the measurement quantity changes—regarding local RF restrictions. Prior to 2020, the ICNIRP SAR was used up to 10 GHz (vs. FCC's 6 GHz), while power density was used above 10 GHz. They noted that the different quantities are used because SAR may underestimate superficial exposures at higher frequencies, whereas power density may underestimate deeper exposures at lower frequencies. As a pragmatic approach, ICNIRP reduced the transition frequency from 10 to 6 GHz to "… provide the most accurate account of exposure overall" [19].

ICNIRP's 2020 update [16–19] includes new allowances for 5G that many find disturbing [20, 42–45]. The new guidelines allow higher power densities above 6 GHz that replaced the SAR values, larger temperature increases in localized areas that may exceed thermal thresholds for both short and long periods of time, and divide skin into different types with different allowances (Type-1 tissue includes all tissues in the upper arm, forearm, hand, thigh, leg, foot, pinna and the cornea, anterior chamber and iris of the eye, epidermal, dermal, fat, muscle, and bone tissue. Type-2 tissue includes all tissues in the head, eye, abdomen, back, thorax, and pelvis, excluding those defined as Type-1 tissue). ICNIRP adheres to a thermal-effects-only model and now indicates assumed safety with increases to 5 °C in skin, the cornea and iris, and bones, as well as a 2 °C increase in brain temperatures on an indefinite basis. Their 1998 guidelines only allowed a 1 °C maximum increase for localized tissue and overall body temperature. Their rationale for the increased 2020 allowances stated that the 1998 safety margins were too conservative. For comparisons between ICNIRP's 1998 and 2020 allowances, see ICNIRP [19], and charts in Leszczynski [46] as well as Hardell et al. [20].

In the U.S., there has been significant longstanding pressure from industry over the years to harmonize FCC standards with ICNIRP—an action that FCC has resisted. As of this writing, which excludes any new standards pertinent to 5G being adopted, the current FCC standards are still more stringent in some frequency bands, exposures, and time allowances than ICNIRP's [47].

Other countries have adopted more stringent standards than FCC or ICNIRP based on different health criteria orientation—some more precautionary than others [25, 48]. There are calls to disband ICNIRP [49] as well as numerous lawsuits in various states of deposition against the U.S. FCC regarding NEPA enforcement (see below), federal preemptions in favor of industry over local/state infrastructure review and siting [50], and the adequacy of FCC's exposure standards [51]. A 2021 court ruling found that the FCC's decision terminating its inquiry into the adequacy of the RF health standards was unlawful [51]. There are other significant issues—such as the defunding of the U.S. EPA for nonionizing EMF research and oversight—that are mentioned in this 2021 case [11].

What wildlife may be experiencing

At a 100–200 ft (30.5–61 m) distance from a cell phone tower/base station (i.e., antennas or antenna arrays), 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. Throughout this three-part series, we defined low-intensity exposure where effects are seen to RFR for power density at 1 μW/cm^2 and a SAR of 0.001 W/kg. The reason for using such a very low level is to show that biological effects have been widely observed much lower than at the 4 W/kg used in standards setting. (For extensive tables of studies that match these low levels, see Part 2, Supplement Tables 1–4).

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 [21]. 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 Part 2 Supplement 3 for broad animal effects and Supplement 4 for flora effects).

Unlike field research, *in vitro* and *in vivo* laboratory studies are conducted under highly controlled circumstances, often with immobilized test animals, typically at near-field exposure, 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. There are also numerous 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 abundant factors.

It is highly likely that the majority of wildlife species are constantly moving in and out of varying artificial fields. Although precise exposure data are difficult to estimate, there is a growing body of evidence that finds damage to various wildlife species near communications structures, especially where extrapolations to, or measurements of, radiation exposure have been made [52–63].

The introduction of 5G broadband using frequencies in the mid-MHz through mid-GHz millimeter wave (MMW) bands—radiating from both land and satellite-based transmitters in urban, suburban, and rural/forested areas —has the ability to impact numerous species at very low intensities based on several mechanisms. These involve a plethora of unique magnetoreception factors in non-human species, depending on taxonomy, size, season, and habitat (see Part 2). Some of these include resonance factors and intense heating effects for some insect species as insects do not dissipate heat and therefore have no thermoregulatory compensatory responses; interference with orientation in some insect and bird species based on the presence of natural magnetite and cryptochrome in their physiologies that enable complex interactions with the Earth's geomagnetic fields and sunlight for all their life's activities; and adverse die-off effects in flora such as trees in close proximity to infrastructure like small cells, to name but a few (see Parts 1 and 2 and their Supplements for a more thorough analysis). 5G's effects on insects alone have the ability to create holes in critical food webs affecting all other species, and ultimately humans.

The exposure allowances used by FCC and ICNIRP are already higher in the MMW bands to be used in 5G. This is based on whole human body resonance factors and partly on efficient skin absorption—estimated at 90–95% MMW incident energy absorbed in human skin [64]. But this simplistic assessment does not factor in that skin tissue—human and some non-human species alike—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 [65]. One study by Cosentino et al. [66] found effects to unilamellar vesicles made of phospholipid—or lipid vesicles—with decreased cell membrane water permeability and partial dehydration of the cell membrane, as well as cell membrane thickening/rigidity seen at 52–72 GHz at incident power densities of 0.0035–0.010 mW/cm^2. Human sweat ducts in particular may act as coiled helical antennas and propagate MMW energy as a waveguide deep into the body at these higher frequency exposures causing uniquely higher SARs [67] not reflected in today's standards. Where there are similar physical characteristics in other species, the above information would also apply.

Because of sub-millimeter depths of penetration in skin tissue with MMW, "superficial" SARs as high as 65–357 W/kg are possible. Eyes are of particular concern in all species. MMW frequencies penetrate less than 1/64 of an inch (0.4 mm)—about the thickness of three sheets of paper. That is thick enough to penetrate deeply into thin-skinned amphibian frog and salamander species, for instance, as well as most flora, and is more than half the depth of some small insects that are primary food sources for other species. The wavelength of MMWs is shorter (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 shorter the wavelength, the higher the energy density per wavelength unit. In this case, with MMWs it is about 25 times higher than with cell technology microwaves [68]. This means MMW are capable of resulting in significant damage throughout the biome, including possibly to all flora and fauna present, but effects are not due to wavelength alone. The multiple biological effects from intense energy absorption at very short wavelengths—e.g., in human skin cells or any thin-skinned species, and especially in insects that 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. In other words, thermal exposure standards that may protect humans against heating have the ability to cause thermal damage to other species with more extreme consequences.

There are other interesting environmental characteristics regarding MMW. For instance, Betskii et al. [69] pointed out that MMW radiation, unlike other frequencies, is virtually absent from the natural environment due to strong absorption by the atmosphere. The authors hypothesized that low-intensity MMW may have broad nonspecific effects on biological organisms and that vital cell functions may be governed by coherent electromagnetic EHF waves. Their study results found alternating EHF/MMWs were used for interaction between adjacent cells, thereby interrelating and controlling intercellular processes in the entire organism. Other authors [70–73] expounded on the idea that because MMW are absent in the environment, living cells may make specific and dedicated use of them. While these ideas are theoretical, they may plausibly explain the high MMW sensitivity observed in biological subjects (see Part 1), especially in human therapeutic applications which have long been popular in Russia.

MMW below 100 GHz are maximally absorbed by water vapor (H_2O) at 24 GHz, and by oxygen (O_2) at 60 GHz [74–76], raising the possibility that 5G could destabilize the climate even more than current trends, especially from satellite transmission. Rain, foliage, and other things easily attenuate MMW signals so 5G must operate at higher power density, as well as utilize different modulation characteristics such as phasing to enhance signal propagation's penetration through physical objects like building walls. At 60 GHz, 98% of transmitted energy is absorbed by atmospheric oxygen. As far back as 1997, the FCC issued a report [74] on MMW propagation characteristics, noting that between 200 MHz and 95 GHz, there was significant signal loss at 40 GHz due to foliage (see Part 1), as well as resonant matches for atmospheric water vapor at 24 GHz and oxygen at 60 GHz.

Despite this, the FCC has already licensed the buildout of 5G in the 24, 28, 37, 39, and 47 GHz ranges thus far with higher bands extending above 95 GHz allocated for future use. FCC has also allocated MMW from 57.05 to 64 GHz for unlicensed use; ICNIRP may follow. Concerns include both land-based networks as well as satellite transmissions. By the time satellite transmissions reach the Earth's surface, the power density is low (see Part 1) 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. Even weak signals from satellites using phased array characteristics may be a significant contributor to species effects in remote regions (see Part 1 and Part 2, Supplement 3).

Much of the research on MMW and phased array with accompanying unusual biological effects—e.g., precursor formation capable of causing deep nonlinear body penetration (see Part 1)—has been done in lossy materials like water. We therefore 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. 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 [77–82].

In addition, Betskii and Lebedeva [83] 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 can 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 a long list of MMW effects that included EHF strong absorption by water and aqueous solutions of organic and inorganic substances; effects 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 were dependent 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. The theory of stochastic resonance playing a mechanistic role in the effects noted in the above study deserves further investigation given its known function in non-human species perception abilities that are used for survival (see Part 2).

And then there's the role of unique wildlife magnetoreceptor cells. Akoev et al. [84] studied MMW effects to the specialized electroreceptor cells called Ampullae of Lorinzini in anesthetized rays (an elasmobranch fish) 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. The authors emphasized they were not observing just a MMW bioeffect but rather a specific response to that frequency range by a unique electro-receptor cell. This one study points out the inadequacy of assuming that MMW's superficial skin penetration is enough to base exposure-standard extrapolations to nonhuman species (For an extensive reviews of other MMW studies pertinent to wildlife, see Parts 1 and 2).

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. In some insect species that would equal deadly whole body resonance exposure [85]. In a study, Thielens et al. [86], 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 2020 follow-up study of RFR, Thielens et al. [87] 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 to 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 [88, 89]. 5G's complex phased MMWs may also be capable of disrupting crucial biological function in other species and critical ecosystems 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 [90] as well as other crucial aspects of avian life.

Any assumed wildlife protection in exposure standards for humans is purely hypothetical at the ecosystem level. 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 (see Parts 1 and 2, plus Supplements). FCC rules do not require an Environmental Assessment (EA) for new towers, for example, unless a proposed structure can be proven to negatively affect birds or other species federally listed as threatened or endangered (see below). EAs as currently applied can include effects from physical tower placement itself, but not typically RFR exposures. As a result, no one is required to assess ambient environmental EMF effects, let alone answer questions about impacts to other species from such technologies (see the Section "Discussion: synthesis of linear and nonlinear disciplines needed" below for some reasons why this situation exists at the federal level). There is a critical hole in our regulatory environmental apparatus when it comes to electroecology.

Regulations and laws pertinent to EMF

There are several significant U.S. federal environmental statutes and their implementing regulations intended to protect wildlife and their habitats. All potentially apply directly or indirectly to the impacts created by EMF if we choose to use these statutes in that capacity. In some cases, treaty protocols and international laws also extend to Canada, Mexico, Russia, and elsewhere. Some states, provinces, counties, and cities also have similar laws in place but space precludes detailed listing here. The focus of the sections below is on key U.S. federal laws and those of Canada and Europe that could incorporate EMF into assessment considerations.

The Endangered Species Act of 1973

While the Migratory Bird Treaty Act of 1918 (MBTA)—discussed in detail below—is the oldest U.S. environmental wildlife protection law, having been enacted over 100 years ago, the Endangered Species Act (ESA) of 1973 (16 U.S.C. 1531 et seq). [91] is considered the key U.S. environmental statute. The ESA is intended to recover plant and animal species from extinction, preventing further extinctions or extirpations, and provides subsequent protections including at ecosystem levels. ESA has been amended many times over the years[1] [92]. Somewhat like the MBTA, ESA was designed to implement an international protocol called the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) [93], which

1 To view the entire contents of each section of the Endangered Species Act of 1973 as amended and to click on a section title below that corresponds with your interest see: https://www.fws.gov/endangered/laws-policies/esa.html. Many section pages include audio or slideshow summaries that provide a more general overview of that section. Or to download the entire Act or individual sections in PDF format from US FWS's document library, go to: https://www.fws.gov/endangered/esa-library/index.html.

itself was designed to protect plant and animal species worldwide through restrictions on such trade.

ESA was implemented to protect all plant and animal species listed as threatened or endangered, and to protect habitats designated as critical. ESA also contains provisions for designating species as *candidates* under Section 4(b)3(A) [94] for possible future threatened or endangered status—i.e., listings that may have been warranted but precluded for one reason or another, or are in need of additional population assessment before determinations can be made. While the process is supposed to be based strictly on sound scientific review and findings, politics have often impacted listing decisions. Nevertheless, since its passage in 1973, some 1,400 plant and animal species have been afforded protections, with many on the path to recovery (e.g., grizzly bears and gray wolves) or fully recovered (e.g., Bald Eagles and Peregrine Falcons). ESA is a longstanding highly successful environmental law.

The ESA is administered by two agencies: The U.S. Fish and Wildlife Service [95] and the U.S. National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) [96]. U.S. FWS maintains a worldwide ESA list of threatened and endangered species and is responsible for overseeing terrestrial and freshwater organisms, including four species of marine mammals—i.e., manatees, polar bears, walrus, and sea otters. The NMFS oversees all ESA listed marine wildlife, including large and small cetaceans, sea turtles, and anadromous and steelhead salmon, as well as some flora critical to marine wildlife survival such as Johnson's sea grass which is important for shelter and sea bottom nursery habitat.

All oversight agencies use the ESA as part of their enforcement toolkit.

The ESA regulations make it illegal to kill, harm or otherwise "take" a listed species. ESA definitions include:

- **"Take":** A "taking" under ESA is defined as to "… harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct."
- **Endangered:** A species is listed as: endangered if it faces a significant risk of extinction in the near foreseeable future throughout all or a significant portion of its range.
- **Threatened:** A threatened species is defined as at risk of becoming endangered in the near future.

The ESA and its implementing regulations include a detailed consultation process. Under Sections 7 and 10 [97, 98] the regulations can authorize "incidental or accidental take." Under Section 7, a federal agency must consult with either U.S. FWS or NMFS (depending on the species and/or habitat affected) and specifically provides that, "… each federal agency shall, in consultation with and with the assistance of the U.S. FWS or NMFS, insure that any action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species which is determined to be critical" [97]. Further, the "action agency," meaning the agency that retains discretionary federal control and is responsible for its actions on the environment, must determine at the earliest possible time whether any listed species or critical habitat may be affected in any manner by the proposed action. In the case of RFR, the FCC is the action agency whose licensing effects from EMFs on ESA-listed migratory birds, for example, must be addressed. That includes radiation from any communications tower, device, or whole communications networks. More specifically, the action agency must consider the *potential* risks/impacts from RFR emitted from towers or other sources. Unfortunately, such determinations have yet to occur for wildlife at FCC. (For an inventory of listed species, see reference [99]).

Under Section 10 of the ESA, private landowners can develop their own habitat conservation plans, which must be approved by U.S. FWS. These may also allow for some level of "take" of listed species [100]. Under Section 11 [101], citizens can file lawsuits against U.S. FWS or NMFS for actions they deem illegal under the statute and such suits may proceed if litigants prove they have legal standing (For some examples of legal suits brought by the Department of Justice, see reference [102]).

For decades, the ESA—a most significant law—has been challenged by politicians, numerous industries, and some public segments, including Congressional attempts to defund the programs altogether. But the ESA is vitally worth protecting and has stood the test of time thus far.

The Migratory Bird Treaty Act (MBTA) of 1918

The Migratory Bird Treaty Act of 1918 [103], as amended, is over 100 years old and still among the most effective laws protecting avian species [26]. Migratory birds—those that migrate across U.S., Canadian, Mexican, and/or Russian borders, of which 1,093 species are currently protected in the United States [104]—are a public trust resource that belong to every U.S. citizen. Almost all native North American continental birds are protected by the MBTA. Exceptions include the Wild Turkey, Asian Pheasant, Lesser and Greater Prairie Chicken, other grouse species, European Starlings, English Sparrows, and Monk Parakeets (among others) which have been accidentally or intentionally introduced to the U.S. The ESA also addresses birds [105].

The MBTA implements/regulates bilateral protocols with Canada, Mexico, Japan, and Russia regarding the shared migratory bird resources of the U.S. and its treaty partners [26]. It is a strict *prima facia* liability statute, meaning that proof of criminal *intent* in the injury or killing of birds is not required by U.S. FWS or the Department of Justice for cases to be made. The statute currently protects migratory birds, their parts, eggs, feathers, and nests, with migratory bird nests protected during the breeding season, while eagle nests are protected year-round. A federal permit is required to "possess" a migratory bird and its parts, but the MBTA contains no provisions for the accidental or incidental "take" (i.e., causing injury or death) of a protected migratory bird, even where normal, legal business practices or personal activities are involved. Bird death, injury, and crippling loss are the only "takings" that matter under the MBTA, not the circumstances under which they occur, although those circumstances can certainly come under investigation.

When the MBTA was enacted, Congress was serious and intended the "take" of even one protected migratory bird to be a violation of the statute, sometimes backed by extensive fines and criminal penalties [26]. Examples include: the 1999 Moon Lake Electric Cooperative fined $100,000 for electrocuting migratory birds; the 2009 criminal settlement with PacifiCorp for $10,500,000 for electrocuting birds (the final settlement resulted in $400,000 in fines, $200,000 restitution to the State of Wyoming, and $1,900,000 to the National Fish and Wildlife Foundation for eagle conservation); and the 2012 settlement agreement with Duke Energy Wind Facility for $1,000,000 for bird deaths from wind turbine blade collisions. All of these settlements involved several years of probation for company executives, and required significant improvements to facilities (an author of this paper was involved with these criminal cases while at the U.S. FWS) [26].

Unfortunately there were recent potentially serious erosions of the legal interpretations involving MBTA. Up until 2017, companies could be fined under criminal misdemeanor provisions when steps to avoid or minimize "take" of birds were not implemented—especially if U.S. FWS's Office of Law Enforcement had made requests to proponents to avoid/minimize dangers and such recommendations were ignored or minimally implemented. In late 2017, the former Trump Administration refused to enforce the MBTA for so-called "accidental or incidental take," while only enforcing provisions for poaching (illegal harvest) and illicit trade in birds and their parts in its then new legal opinion (M-37050). But on March 8, 2021, under a new Administration, the U.S. Department of the Interior withdrew M-37050 after a U.S. District Court invalidated the rollback of the MBTA [106] (One of the authors of this paper was involved in these court cases).

The MBTA has no consultation process like that under ESA's Section 7, and it does not authorize "incidental or accidental take" which ESA does under ESA Sections 7 and 10 [26, 97, 98]. Where "take" was likely to occur under MBTA, various agencies, entities, and individuals were working proactively with U.S. FWS (especially its Office of Law Enforcement, Ecological Service Field Offices, and Division of Migratory Bird Management) to implement all necessary and appropriate steps to avoid or minimize any future damage to birds. MBTA was intended to protect all migratory birds—no excuses accepted but solutions were appraised by U.S. FWS officials—while the ESA allowed some room to negotiate and remediate. But M-37050, as discussed above, until it was invalidated by the court and withdrawn by the Department of the Interior [106], completely upended that protective balance, demonstrating how fragile some of these longstanding effective laws can be due to political caprice. Both the ESA and MBTA could pertain to ambient EMF if applied that way.

Birds of Conservation Concern: how U.S. agencies track non-listed but imperiled migratory birds

There are two primary ways that U.S. federal agencies keep track of birds. In addition to ESA-listed birds, the U.S. FWS maintains the list of Birds of Conservation Concern (BCC) [107]. There are currently at least 147 species designated nationally of the 1,093 species now protected and the number grows with each BCC update [104]. When U.S. FWS regional lists are included in the overall tally, there are some 272 BCC species (>26% of all protected birds) designated in trouble [104]. BCC lists require periodic reviews/updates under provisions of the Fish and Wildlife Conservation Act (16 U.S.C. 2901–2912) [108]. The overall objective of the U.S. FWS is to maintain bird populations at stable or increasing numbers—a daunting challenge due to both direct and indirect impacts, including EMFs discussed in detail in Part 2. The BCC list is designed to serve as an early warning system of birds in trouble but not yet candidates for listing under the ESA [26]. A species designation on the BCC list could impact both infrastructure siting as well as potentially measured or modeled/projected rising ambient EMF levels in some regions (see Part 1).

Federally listed bird species are those protected under the ESA. On the List of Threatened and Endangered Species, there are currently 77 endangered and 15 threatened birds [104]. An endangered species faces significant risk of extinction in the near foreseeable future throughout all or a significant portion of its range, while a threatened species is at risk of becoming endangered in the near future. Extinction is irreversible and permanent.

Collectively, migratory birds are in decline, some precipitously (see Part 2), with numbers of both listed and BCC species increasing [26, 107]. With 272 BCC-designated species and 92 Federally Endangered and Threatened migratory birds, out of 1,093 protected migratory birds, at least 364 (>33%) species are in trouble. Those numbers continue to increase at a sizable rate and once a bird population is in trouble, reversing its decline is extremely difficult [26, 109, 110]. The MBTA has no provisions for acquiring and protecting bird habitats although there have been bilateral discussions between the U.S., Canada, Mexico, Japan, and Russia that have resulted in some bird habitat protection efforts.

Other protections: presidential Executive Order 13186—Migratory birds, and The Bald and Golden Eagle Protection Act

In January 2001, the Migratory Bird Executive Order 13186 [111] was signed by President Clinton. It stipulates that, "… each Federal agency taking actions that have, or are likely to have, a measurable negative effect on migratory bird populations …" is to develop and implement a Memoranda of Understanding (MOU) "… to promote the conservation of migratory bird populations." Simply put, if the actions of a federal agency are now, or will in the near future, impact bird populations, that agency is to sign and implement an MOU with the U.S FWS in an effort to protect migratory birds and their habitats [26]. While many of the previous Executive Orders in place from the Clinton, Bush, and Obama administrations were rescinded by the Trump Administration, E.O. 13186 was not among them. An executive order from the White House does not have the full force of a law implemented by the U.S. Congress, but in this case E.O. 13186 does have the force of the MBTA clearly backing it. E.O. 13186 provides specific opportunities for habitat protection, land management, and conservation planning. U.S. FWS has the responsibility under the E.O. to protect migratory birds and their habitats.

In addition to protections under the MBTA, the U.S. FWS is also responsible for maintaining stable and/or increasing breeding populations of Bald (*Haliaeetus leucocephalus*) and Golden (*Aquila chrysaetos*) Eagles under The Bald and Golden Eagle Protection Act [112, 113]. The definition of "take" under BGEPA is broader than under MBTA, and includes provisions against pursuit, shooting, poisoning, capturing, killing, trapping, collecting, molesting, and disturbing both species (ref. [112], 50 C.F.R. 22.3). Permits are required from U.S. FWS for "disturbance take" and "take resulting in mortality" (ref. [112], 50 C.F.R. 22.26), and for "take of nests" (ref. [112], 50 C.F.R. 22.27). Disturbing, injuring or killing eagles without an "eagle take" permit under BGEPA could result in criminal culpability. Any infrastructure-related EMF effects to Bald or Golden Eagles would be actionable under these regulations.

The National Environmental Policy Act: how it applies to environmental EMF and categorical exclusions

The second most iconic U.S. environmental law, after the ESA, is the 50 year old National Environmental Policy Act [114, 115]. Among the most effective laws ever passed, it was signed by President Nixon in 1970 and has become an important means for protecting wildlife in the face of large government actions. As such it is a constant target for various industries regulated by the government, most recently the telecommunications industry seeking exemptions from the FCC for any effects from their operations, including RFR [50].

NEPA has been applied to any major federal, state, or local project where a federal regulatory nexus or action is involved, including actions taken by federal agencies themselves. This includes:

- Where federal funding had been, is, or will be used.
- Where a permit has been issued by a federal agency.
- Where work or action by a federal agency has been contracted for a project [26].

Courts have also expanded the purviews of NEPA. In addition, the NEPA legislation established the Council for Environmental Quality (CEQ) which is housed within the U.S. Executive Office of the President to advise the President on the state of the environment and environmental policy.

The primary role of NEPA rules is to establish national environmental policy and to determine the regulations that require all federal agencies to prepare EAs, and/or Environmental Impact Statements (EISs) that accompany official reports and/or recommendations whenever they are submitted to Congress for funding. A vast array of federal agencies is involved in NEPA review/compliance, including agencies like the Environmental Protection Agency (EPA) and U.S. FWS.

Unlike MBTA and BGEPA, which are both strict liability statutes (see above), NEPA regulations have no criminal or civil penalties or sanctions. As such, all enforcement of NEPA must go through the courts which may order a federal agency to require a proponent to perform NEPA-compliant analysis and performance. This would include, for instance, compliance with the previously described bird protection laws where migratory birds could be impacted by EMF and other radiation exposures.

To effectively apply NEPA, an evaluation is required of the relevant environmental effects of a federal project. For instance, in the case of environmental EMFs, assessing the impacts of 5G on wildlife (including insects and migratory birds), NEPA review should be performed by the FCC before instituting any rulings that would facilitate 5G buildout, or an evaluation of an action mandated by NEPA where the "nexus" conditions apply. This process begins when an agency or commission, such as the FCC or the Federal Energy Regulatory Commission, develops a proposal that addresses the need to take an action. If that action is covered under NEPA, three levels of analysis are required by the action agency (i.e., the agency with responsibility for its action on the environment) for that action to be in compliance with NEPA. These include where applicable:

- Preparation of a CatEx.
- Preparation of an EA.
- The determination of either a Finding of No Significant Impact (FONSI) or …
- The preparation/release of an EIS if there will likely be significant impact to species or habitats.

Because NEPA allows public review and comment on these documents and the process, this provides a venue for litigation and possible court action.

A CatEx [116] is a list of actions that an agency has determined do not individually or cumulatively significantly affect the quality of the human environment ([116], 40 C.F.R. §1508.4). A lot of things can slip through the cracks with such exclusions. The "quality of the human environment" represents a key phrase in interpreting NEPA. As such, if a proposed action such as the use of 5G and its impacts on wildlife were to be included in an agency's CatEx—say by FCC and U.S. FWS—the agency must ensure that no extraordinary circumstances might cause the proposed action to affect the environment (in this case, humans and wildlife). Extraordinary circumstances include negative effects/impacts on endangered species, protected cultural sites, and wetlands. If the proposed action is not included in the description provided in the CatEx, an EA must be prepared and can be published in the *Federal Register*, which allows the public to comment, and if necessary, to litigate. (Notice of all EISs must be published in the Federal Register; some, but not all, agencies choose to also publish notice of EAs—no absolute requirements to do so exist. The Council of Environmental Quality [CEQ] regulations also do not mandate notice of EAs—only EISs).

The release of an EA and a FONSI represent specific public documents which include information on the need for a proposal, a list of alternatives, and a list of agencies and persons consulted in the drafting of the proposal. "The purpose of an EA is to determine the significance of the proposal's environmental outcomes and to look at alternatives for achieving the agency's objectives. An EA is supposed to provide sufficient evidence and analysis for determining whether to prepare an EIS, aid an agency's compliance with NEPA when no EIS is necessary, and it facilitates preparing an EIS when one is necessary." [115, 116].

If it is determined that a proposed federal action does not fall within a designated CatEx or does not qualify for a FONSI, then the responsible agency—which in the case of 5G buildout would involve the FCC with significant input from U.S. FWS—must prepare an EIS. The purpose of an EIS is to help public officials make informed decisions based on the relevant environmental consequences and the alternatives available.

From the information presented in Parts 1 and 2 of this paper and elsewhere, the environmental consequences of 5G and rising background levels of RFR could be catastrophic to some species. The drafting of an EIS includes public parties, outside parties, and other federal agency input concerning its preparation. These groups subsequently comment on the draft EIS. However, the FCC has systematically categorically excluded many devices and current technologies that use RFR, as well as ruling that their exposure standards extend to 5G exposures [4, 117], thus allowing their use/buildout to proceed without full NEPA/EIS review.

Even when NEPA has been applied to an RFR exposure situation, there have been problems. Part 1 included discussion of a U.S. military training proposal throughout a protected wilderness area that involved a lengthy, but ultimately inadequate, NEPA review with the U.S. FWS (see Part 1 for further details). What that case revealed was the necessity for environmental agencies to have their own in-house bioelectromagnetics expertise with knowledge of nonionizing radiation effects to wildlife—something now lacking throughout regulatory agencies. In light of continuing new information, to do otherwise fosters large loopholes through which entire networks of low-power infrastructure can avoid larger environmental review.

It is important to note, as described above, that all small cells intended for 5G deployment, are categorically excluded by the FCC, thereby bypassing NEPA requirements despite significant studies (see Part 2) of adverse effects to all taxa that would apply for review under EAs, and EISs. Part 1 explored measured levels from the 1980s to today's measured rising background RFR that should also apply to NEPA review, given the expansion of a large new technology like 5G about to make its own significant contribution. Instead, FCC categorically excluded small cells from NEPA without any examination of the unique signaling characteristics of 5G that are new to broadband telecommunications technology in the built environment, or 5G's higher frequencies to be used widely at significant scale that may especially impact insects and birds (see above, "Government exposure standards"). Instead, FCC ruled that states and municipalities must streamline small cell network applications and buildouts without NEPA [117]—a position that was successfully challenged in U.S. courts [50].

At the moment, NEPA requirements still stand. But other suits challenging FCC's small cell streamlining without also updating their exposure standards were less successful [118]. Under the former Trump Administration, industry-friendly legislation was introduced [119] that would have excused the FCC from all NEPA review as a matter of course. No other federal agency with the ability to impact the environment had ever gotten such a pass. The bill did not succeed but such an attempt again demonstrates the fragility of these iconic environmental protections.

Canada's environmental laws and regulations: Species at Risk Act, and Migratory Birds Convention Act

In conjunction with U.S. laws that are observed across borders, Canada has some strong regulations of its own such as the Species at Risk Act and the Migratory Birds Convention Act (MBCA).

The Species at Risk Act, known as SARA [120], is similar in many respects to the U.S. ESA. SARA encourages the various government entities in Canada—e.g., Provincial, Federal, First Nations, territorial, county, city, town, and fort—to cooperate in protecting wildlife species in Canada. SARA also includes protocols for consultation and cooperation with Aboriginal/First Nations peoples which Canada views as essential to successfully implementing the statute.

Like the U.S. ESA, SARA can affect entities or individuals who own property or have a vested interest in land where a species at risk (designated in the List of Wildlife Species at Risk [121] is found at any time throughout the year. The statute also defines critical habitat, designated in the SARA Public Registry [122]. Like the purposes of the ESA, SARA is intended to prevent wildlife species in Canada from disappearing; to recover wildlife species extirpated (i.e., no longer found in the wild in Canada), endangered or threatened as a result of human activity; and to manage species of special concern so as to avoid threatened or endangered designation [123]. To accomplish these purposes and goals, SARA establishes how governments, organizations, and individuals in Canada should work together, and establishes guidelines for implementing a species assessment process to ensure the protection and recovery of species. Like the ESA, SARA incorporates penalties for violations; and like NGOs in the U.S. that support/publicize specific issues pertaining to threatened and endangered species, Canada also has NGOs doing the same thing [124].

Canada's Migratory Birds Convention Act (MBCA) of 1994

As with the U.S.'s MBTA, the vast majority of bird species in Canada are protected by the 1994 MBCA [125]. Passed in 1917 and updated in 1994 and 2005, MBCA implements the Migratory Birds Convention, a treaty signed with the United States in 1916. The Canadian Federal government is authorized to pass, implement, and enforce Migratory Bird Regulations [126] designed to protect the species included in the Convention. The lists of bird species protected by Canada and the U.S. may be different. Bird species that are not listed in Canada or the U.S., and/or defined under Article 1 of the MBCA, may or may not be protected by Provincial or territorial legislation, or by SARA, or the UN Convention on Biological Diversity [127] which is an international legal instrument for "… the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" that has been ratified by 196 nations [128].

Persons, industries or other entities making any decisions (e.g., installing cell towers) that would impact the protected status of a bird species in Canada should also consult SARA. Environment and Climate Change Canada requires that three criteria be met to qualify for the list of bird species protected in Canada under the MBCA. They include:

(1) Birds designated in Article 1 of the MBCA as amended under the 1995 Protocol [128].
(2) Species native or naturally occurring in Canada noted under regulations.
(3) Species known to regularly occur in Canada. Although species that occur infrequently (i.e., "accidentals") and that meet criteria 1 and 2 are not included on this list, they continue to be considered as having protection under the MBCA any time they occur in Canadian territory.

While birds such as grouse, quail, pheasants, ptarmigan, and turkeys—which also in the U.S. are not migratory and/or have been introduced (e.g., pheasants)—are not protected under MBCA nor the MBTA, in Canada birds such as hawks, owls, eagles, falcons, cormorants, pelicans, crows, jays, kingfishers, and some species of blackbirds are also not protected under MBCA. This represents a significant difference between MBTA protection in the U.S., and eagle protection under the U.S. Bald and Golden Eagle Protection Act (discussed above) where all birds in the latter category are protected in the United States.

There are three introduced bird species that do not meet criterion 2 above, but continue to appear on the MBCA list. They include the Mute Swan (*Cygnus olor*), the Eurasian Collared-Dove (*Streptopelia decaocto*), and the Sky Lark (*Alauda arvensis*). Environment and Climate Change Canada [128] continues to consult with provincial and territorial governments, which share responsibility for the management of birds in Canada, regarding a proposal to remove these species from the list of MBCA birds. Until a decision is reached by the concerned parties, these three species will remain under MBCA protection. The list of birds protected under the MBCA follows the American Ornithologists' Union's Check-list of North American Birds, and its supplements to 2014, on matters of taxonomy, nomenclature, and sequence [129].

European environmental laws: European Union (EU) initiatives addressing endangered species and habitat protection

The EU, with its 27 member nations, has recently implemented a four-pronged approach to better address species protection, recovery, and restoration of imperiled plants and animals found on the continent [130, 131]. This includes:

– Species protection through a Birds Directive.
– Species protection under a Habitats Directive.
– Ensuring that plants and animals are not threatened by illegal and/or unsustainable international wildlife trade through stronger implementation of CITES—the Convention discussed above [93].
– Developing and implementing an EU pollinators initiative to reverse negative impacts to pollinators including effects from EMF/RFR [132].

The EU began an ambitious effort in 2011 to develop and implement a Biodiversity Strategy to institute the framework for this four-pronged approach above. The Strategy includes the following targets:

(1) Protect 100% more habitats and 50% more species above 2011 levels.
(2) Establish green infrastructure and restore at least 15% more ecosystems.
(3) Achieve more sustainable agriculture and forestry.
(4) Make fisheries more sustainable and the seas healthier.
(5) Combat invasive alien species.
(6) Help stop or reverse the global loss of biodiversity.

At this writing, the EU may still be on track to achieve their strategy, although progress calls for a much greater effort among all parties involved, and the transition from BREXIT is creating many difficulties, unknowns, and complexities [130–132].

It is clear that all industrialized Western countries are trying to address serious environmental issues with more and/or less success—depending on politics, funding, and the will to act. EMF as an environmental pollutant needs to be part of that effort.

Airspace as habitat: aeroecology

Birds, bats, insects, and other species that use airspace for critical life functions are of cornerstone significance to us all. Birds, for instance, provide key ecosystem functions that fuel multi-billion dollar industries through pollination and insect/weed/seed control in the agribusiness sector, as well as in the forestry industries. Without migratory birds, there would be untold problems and money spent globally for more pesticides, herbicides, and other chemicals. In addition, in the U.S. alone, feeding, photographing, and observing birds fuels a $32 billion annual recreation industry, representing 20% of the U.S. adult population engaging in these activities. Human/bird-related activities are reportedly more popular than golf [26, 133].

Birds also have spiritual significance to indigenous peoples. A number of migratory bird species—notably Bald and Golden Eagles, Common Ravens (*Corvus corax*), American Crows (*Corvus brachyrhynchos*), hawks, falcons, doves, owls, and hummingbirds—are revered and protected by the Tribal laws of several U.S. indigenous American Tribes and Canadian First Nation peoples. Some of these very species are at considerable risk from habitat disturbance/fragmentation, injury, and death, including from EMF and other radiation impacts which will undoubtedly increase exponentially without a change in human awareness.

We have a legal, moral, and ethical obligation to protect migratory species of every kind, the airborne included. Impacts from EMF may add to species declines and ultimately threaten their survival if we do not understand and respond appropriately because airspace is as critical a habitat as are water and soils for non-airborne species. Thus far we have failed to muster the macroscale vision of the air-as-habitat concept that also includes flora, which are exquisitely sensitive to the ELF of the Earth's geomagnetic fields with their root systems underground as well as to RFR with their primary stem and leaf growth in the air (see Part 2 and Part 2 Supplement 4). Humans have collectively done a poor job of addressing impacts to living organisms that use the airspace—most especially migratory birds, bats and beneficial insects—along with being negligent in protecting what is on, as well as below, the ground, and in aqueous environments. We need to understand EMF as a form of energetic air pollution, especially biologically active anthropogenic RFR that is endemic today in airspace.

Defining the habitat of airspace

The airspace used by plants and animals includes the space just above ground level (AGL) to ceilings in excess of 26,245 ft (8 km) AGL. These upper ranges are used, for example, by Demoiselle Cranes (*Grus virgo*) and other migratory bird species, as well as Golden Eagles which prey on the cranes and other quarry. But airspace should be considered as habitat for a variety of plants and animals too that use and depend on it during, and in some cases throughout, significant portions of their lives. These living organisms include, but are not limited to, flying insects, some arachnids, birds, bats, flying squirrels, flying fish, and some reptiles, as well as seeds, spores, vegetative plant parts, and forest canopies. Organisms use airspace for purposes of transport, dispersal, feeding, mating, territorial defense, escape, migration, daily movements, and for other reasons [134]. In most cases, unimpeded airspace is critical to mating, nesting, survival, food acquisition, territorial defense, daily movements, and migrations of birds and bats (including microchiropterans and megachiropterans) [27, 109, 110].

Impacts to species using airspace have been well documented, including of migratory birds and communication towers and their guy-wire support structures [135]—annual mortality now conservatively estimated at 6.8 million birds killed in the U.S. and Canada solely from collisions with communication structures [136–139]. However, the impacts to migratory birds, other wildlife, and plants generally do not include adequate cumulative effects analyses (cumulative biologically and under the legal mandates of NEPA). Cumulative effects under NEPA must consider and evaluate all impacts from all human-built structural sources including EMFs that they may emit and/or receive, where applicable.

Currently, environmental impacts from RFR on wildlife are not being assessed by the FCC, EPA, or the Department of Interior (DOI), nor is ELF-EMF being considered by the Department of Energy (DOE) regarding powerline exposures. However, it is important to note that precedent was set in 2014 when DOI publicly charged that the FCC's standards for RFR from cellular towers were outdated, based on narrow thermal heating effects, and inadequate to protect migratory birds and other wildlife [139]. A letter from DOI's Director of the Office of Environmental Policy and Compliance was sent in February 2014 to the National Telecommunications and Information Administration (NTIA), housed in the Department of Commerce [140]. The letter—and subsequent meetings with staff from the U.S. FWS—resulted in the initiation of an EIS process under NEPA by NTIA to begin an independent research study to address the impacts of radiation from cell towers on migratory birds using the airspace. Unfortunately, efforts languished and were completely suspended under the former Trump Administration with nothing similar initiated subsequent to that as of this writing. Under NEPA, cumulative effects must include impacts from all human-related sources that affect humans, wildlife, plants, and all living organisms that depend on/use airspace for survival. The effects of EMF on flora and fauna remain widely unassessed [27, 110].

Air as an actual habitat is a relatively new concept for many in the scientific community, including federal agencies such as U.S. FWS whose goal (including for wildlife that use the airspace) has been to "do no harm" [141]. Reducing harm to wildlife that use the airspace is a tall order because a lot of things occupy it—both permanently and on a temporary basis—but we do not generally think of it that way. Airspace interference and adverse effects to wildlife comes in many forms. For instance, in addition to the communication-tower bird-collision mortality estimates referenced by Longcore et al. [138] above, Manville [142] estimated that 440,000 protected migratory birds were killed annually by blade strikes at U.S. commercial wind energy facilities in 2008. Smallwood [143] increased that estimate to 573,000 bird fatalities per year (including 83,000 raptor deaths) based on increases in commercial wind turbines, and estimated that an additional 888,000 bats died in turbine blade collisions annually in the U.S. In addition, based on the variety of survey methods used, differences in survey detail, longevity of assessment, and robustness, as well as differences in infrastructures being investigated, Loss et al. [144] estimated between 8 and 57 million birds are killed annually by collisions with power distribution and transmission lines, and between 0.9 and 11.6 million birds die from wire and infrastructure electrocution each year in the U.S. This is not to mention the estimated 1.4–3.7 billion birds (median = 2.4 billion) killed annually in the U.S. by domestic and feral cats at ground level and/or near-ground while birds are in flight [145]; or the annual estimated 97.6–976 million U.S. bird deaths from building window collisions [146] which Klem and Saenger [147] later estimated was greater than any other source of human-associated bird mortality. Taken collectively, this is massive anthropogenic-caused avian mortality, all of which occurs within the airspace. There are reduction strategies for some of these—like keeping domestic cats indoors and/or placing bells on their collars, installing non-reflective window panes, and using vertical axis designs in wind turbines—but these do not substantially solve the problem. ELF and RFR problems can only be handled at the transmission source through use reduction. Approaches that use frequencies such as radar to repel birds only create an additional ambient source capable of affecting another species, such as insects, in a different way.

The staggering avian mortality rates noted above fail to include impacts from pesticides, contaminants, oil spills, disease, parasites, natural mortality, predators, entanglement, and other non-airspace related sources. Impacts to individual animal and plant species are cumulative. The potential role that EMF plays in adverse effects to animals that use the airspace should be added to the list as a growing concern based on evidence presented throughout this three-part series of papers, and elsewhere.

Aeroecology—a macrovision

The interdisciplinary field of aeroecology has evolved to encompass a variety of issues affecting airspace. The concept was founded around 2008 by Dr. T.H. Kunz, Professor of Biology and Director of the Center for Ecology and Conservation Biology at Boston University who sadly died from Covid-19 complications in April 2020. Kunz laid out an aeroecology vision that includes technological solutions for studying animals that use the aerosphere as well as the key questions that unite aeroecology. Frick et al. [148] wrote an excellent review of this emerging unifying discipline.

Aeroecology integrates domains that include atmospheric science, animal behavior, ecology, evolution, earth science, geography, computer science, computational biology, and engineering [134, 149, 150].

In 2008, Kunz and colleagues organized a symposium in San Antonio, Texas, entitled, “Aeroecology: Probing and Modeling the Aerosphere: the Next Frontier.” At that symposium and since, the concept evolved to define the field, including:

- The aerosphere comprises one of the three major components of our biosphere, yet it is one of the least understood substrata of the troposphere, especially in regard to how organisms interact with and are influenced by this highly variable and fluid environment [134].
- The biotic interactions and physical properties in the aerosphere provide significant selective pressures that influence the size and shape of organisms, as well as important influences affecting their behavioral, sensory, metabolic, and respiratory functions.
- While organisms that spend their entire lives on land or in the water tend to be less varied based on adaptive pressures, organisms that use the airspace can be immediately affected by the changing boundary layer conditions of the airspace.
- These conditions include winds, air density, oxygen concentrations, precipitation, air temperature, sunlight, polarized light, and moonlight, as well as geomagnetic and gravitational forces [134].

The authors of this paper would add to that growing list the impacts of ELF and RFR to organisms that use the airspace at varying durations and intensities.

The discipline of aeroecology allows us to better assess the impacts from anthropogenic factors affecting wildlife that use the airspace—ranging from nearly all, or significant portions of their lives, to minimal amounts of time. While no organism spends its entire life in the aerosphere, anthropogenic factors located within, or that directly or indirectly affect, the aerosphere can have significant impacts. These anthropogenic factors, for example, include skyscrapers, office buildings, homes, structural lighting, city/community lighting, power transmission and distribution wires and infrastructure, radio/television/cellular/emergency broadcast communication towers and structures, commercial wind turbines, industrial solar arrays (especially 'power' towers and large solar panel facilities), bridges, aircraft, air pollution, increases in greenhouse gases, climate change, and radiation emitted from communication structures and related devices, among others [26, 137]. Staff at U.S. FWS emphasized the importance of airspace as habitat, and garnered the attention of top service officials to respond through improved voluntary guidance addressing the various industries impacting airspace.

To study the impacts of communication structures on migratory birds (including from RFR), the U.S. Forest Service invited the Division of Migratory Bird Management at U.S. FWS, to design and develop a research protocol to study towers in several national forests in Arizona. While the protocol, which was written by one of the authors of this paper while at the U.S. FWS [151], would benefit from updating and peer-review, it nevertheless provides a framework for independent studies of EMF impacts to migratory birds, mammals, and other wildlife and plants in the field.

It is important that future studies be conducted by independent scientific sources without vested interests in the outcome. Such inquires clearly fall under the auspices of aeroecology. We first need the vision and will to move this forward.

Discussion: synthesis of linear and nonlinear disciplines needed

Nonionizing EMF is virtually uncontrolled as an environmental pollutant. This was observed as far back as the 1970s [152] and has only gotten progressively worse with each passing decade. There are several reasons for this, including the likelihood that in many regulatory agencies there is an assumption that the science is not robust or adequately developed upon which to base regulations, much less enforce them. There is also a pervasive attitude that risks to wildlife, if any, are minor compared to the human benefits of widespread wireless technology. Technology is seen as beneficial in many environmental circles for the information it can provide, for instance, via animal tracking devices (see Part 1), while potential adverse effects that create hidden variables from such devices rarely occur to environmental researchers. The need to study EMF effects is not obvious to many regulators or environmentalists. That may change once air is understood as 'habitat' and EMF is seen as an energetic pollution source.

Wildlife has also historically been considered resilient (despite much evidence to the contrary) and nonionizing radiation has been seen as relatively harmless beyond tissue heating and electric shock. If non-human species have been considered at all regarding EMF, broad but inaccurate assumptions have been made that protecting humans from the worst adverse effects also extend to other species. What has been lacking is the right government agency expertise with an understanding of how non-human species interact with exogenous EMFs, and at what intensities. There has never been funding in any agency to track or develop that area of interdisciplinary knowledge because the need was not obvious until recently. Other than at the FCC which is mostly staffed with engineers who lack knowledge of biology, civil scientists who are trained in bioelectromagnetics and/or biophysics are found throughout many regulatory agencies. Their work, however, is primarily focused on human health issues, not wildlife. Agencies tasked with wildlife protection have been completely defunded for such work—i.e., the U.S. FWS which does not have a bioelectromagnetics expert on staff, and most importantly the U.S. EPA which at one time had the world's foremost bioelectromagnetics basic research laboratory staffed with scientists who made groundbreaking discoveries (see Part 2, Mechanisms). Many agencies have simply not replaced what little bioelectromagnetics expertise they have had when those scientists retire and new ones have not been trained or hired. And it is only recently that environmental nonionizing radiation has increased to measurable levels high enough to warrant investigation to all living beings. Europe, for instance, is now taking an interest in potential 5G effects and developing standards that apply to wildlife protection [153].

One aspect of rising environmental EMF levels may, however, spur attention—the shadow role it could be playing in global climate change. Scientists know that what occurs in the ionosphere directly affects our weather patterns—of sudden importance given the dramatic increase in satellites being deployed globally for 5G telecommunications (see Part 1). Erratic weather and its consequences have grown to dangerous levels in most parts of the world. Thunderstorms increased 25% over

North America between 1930 and 1975, vs. between 1900 and 1930 [154]. That period directly parallels our first introduction of environmental EMFs along with other contaminants. As far back as 1975, a team of researchers at the Stanford University Radioscience Laboratories, then headed by Robert Helliwell, found evidence that powerline emissions are amplified within the magnetosphere [155], causing a veritable rain of electron precipitation into the ionosphere, which could theoretically lead to both highly localized as well as global changes in weather patterns. The technologies we have added since 1975—both ELF and RFR—which we assumed to be atmospherically benign, may not be as harmless as originally thought. The exponential growth planned for 5G broadband (including MMW) from satellites and millions of accompanying ground-based transmitters is certainly reason for caution. It is already well established that MMW bands at 60 GHz are maximally absorbed by atmospheric oxygen (O_2), as well as by H_2O at 24 GHz—ranges planned for 5G (see Part 1). Oxygen molecules readily absorb the 60 GHz frequency range and rain droplets easily attenuate signals [74–76, 156, 157]. In fact, 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 (see Part 1).

There is a need to re-integrate biology, which studies whole dynamic living systems, with the non-living sciences of physics and engineering that focus on how to create and make technology work. The latter have dominated EMF research and its applications in every way since the 1940s, including research protocols regarding human health and standards setting which are outside their areas of expertise. Today, physics and biology—although fundamentally very different disciplines with their own inherent cultures and biases—increasingly converge when it comes to environmental concerns. While we already understand how to make modern societies and accompanying technologies work, the most important questions now concern the potential effects to the living systems in the path of technology.

Electromagnetism is fundamental to life—indeed all living things function with biological microcurrent without which life would not exist. Technology, which also requires EMF to function, therefore speaks the same fundamental language as living cells. Yet biologists have consistently been left out of full participation in safety and environmental issues in anything other than cursory inclusion. If there is to be a better integration of physics and biology, it will need to be at the behest of the biology community. The physics/engineering disciplines have had the subject to themselves for decades and are somewhat territorial about it. Plus their inherent focus is on linear cause-effect dosimetry models in both technology design and exposure standards setting. They tend be less interested in the confounding complexities of biology which are mostly nonlinear and unpredictable.

The natural world typically demonstrates nonlinear dynamics, meaning that a small stimulus can result in a large, seemingly disproportionate outcome. The weather is nonlinear, for instance, as illustrated by the imagined "butterfly effect" in which a butterfly can theoretically flap its wings in Indonesia and cause a hurricane on the other side of the globe [158–160]. Some disease states are nonlinear, allergies being a prime example. A person with a severe peanut allergy can go into anaphylactic shock by merely being in the same room with the offending agent. Or someone with an allergy to bees, upon experiencing a sting, will react far out of proportion to the tiny amount of venom being injected by the insect. Physics and engineering, on the other hand, are highly linear—an exemplary asset in that realm. Humanity, after all, has no patience for machines or systems that don't work [161].

Until there is a synthesis between physics/engineering and biology, with an emphasis on nonlinear models, the potential environmental effects of our increasing EMF exposures will not be well understood. Each area has much to learn from the other. Biologists can benefit from the precision emphasized in physics and engineering while physicists and engineers can benefit for the savvy that biologists have acquired in environmental observation, measurement, quantification, hypothesis testing, and formulating policy in the face of scientific uncertainty.

Given the rising background levels in urban, rural, and some wilderness environments, EMF should be classified as an energetic air pollutant capable of adversely affecting wildlife and habitats as delineated throughout these papers. Cumulative effects should be taken into consideration from myriad sources, and continuing evidence should be evaluated by unbiased entities, including governments and NGO's. We can no longer presume that the status quo of ever-increasing EMF ambient levels is safe without much closer scrutiny.

Some solutions

Existing environmental laws in the U.S., Canada, and throughout Europe should be enforced. For example, in the U.S., NEPA and its EISs should be required each time a new broadly polluting EMF technology like 5G is introduced, not as the current policy is being interpreted through

"CatEx" or simple dismissal. EISs should be required for all new technologies that create pervasive ambient EMF such as 'smart' grid/metering, Distributed Antenna Systems (DAS), small cell networks, and the 5G "Internet of Things." Where wildlife species are affected, systems and networks that currently meet radiation levels for CatEx (and are therefore exempt from review) should be required to develop/implement NEPA and EIS reviews for cumulative exposures to wildlife from multi-transmission sources.

Efforts should begin to develop acceptable exposure and emissions standards for wildlife, which today do not exist. Setting actual exposure standards for wildlife will be an enormous challenge, and for some species there may be no safe thresholds, especially with 5G and MMW. We may simply need to back away from many wireless technologies altogether, especially the densification of infrastructure, and refocus on developing better dedicated wired systems in urban, suburban and rural areas. Environmentally sensitive wilderness areas should be considered off limits for wireless infrastructure. Once air is seen as 'habitat,' there may come a time when a cell phone call voluntarily *not made* will be understood as removing something detrimental from air's waste-stream, the way we now see plastic bags regarding terrestrial/aquatic pollution.

There are some reasonably simple things that can be done in the ELF ranges that would benefit insect, bird, and many wild mammal and ruminant species. For example, high-tension electric utility corridors can be built or changed to cancel magnetic fields with different wiring configurations. This is already widely done in the industry for other reasons but it also coincidentally eliminates at the source at least the magnetic field component for wildlife. There are other approaches too but further discussion is beyond the scope of this paper.

Research into the long-term, low-level ambient exposures to humans and wildlife is imperative given the picture that is emerging. There is a likelihood that low-level ambient EMF is a factor, or co-factor, in some of the adverse environmental effects we witness today—many previously discussed in this series of papers. There is currently no research in any industrialized country that looks to the broader implications to all flora and fauna from these rising background levels, even as effects to individual species are observed. This is an important, emerging environmental issue that must be addressed.

Conclusions

In this broad three-part review, we sought to clarify if rising ambient levels of EMF were within the range of effects observed in *in vitro, in vivo*, and field studies in all animal phyla thus far investigated. We further discussed mechanisms pertinent to different animal physiology, behavior, and unique environments. The intention was to determine if current levels have the ability to impact wildlife species according to current studies. The amount of papers that find effects at today's EMF levels to myriad species is robust. Some unusual patterns did emerge, including broadly in flora that react beneficially to static EMF but adversely to AC-ELF and especially to RFR.

There is a very large database supporting the hypothesis that effects occur in unpredictable ways in numerous species in all representative taxa from modern ambient exposures. Associations are strong enough to warrant caution. New enlightened public policies are needed, as well as existing laws enforced, reflecting a broader understanding of non-human species' interactions with environmental EMF. Emerging areas, such as aeroecology, help define airspace as habitat and bring better awareness of challenges faced by aerial species—including animals and plants. But we are in the nascent stages of understanding the full complexity and detailed components of electroecology—the larger category of how technology affects all biology and ecosystems.

Historically, control over the realm of nonionizing radiation has been the purview of the physics and engineering communities. It is time that the more appropriate branches of biological science, specializing in living systems, stepped up to fill in larger perspectives and more accurate knowledge. We need to task our technology sector engineers to create safer products and networks with an emphasis on wired systems, and to keep all EMF exposures as low as reasonably achievable.

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References

1. Zipse DW. Death by grounding. In: PCIC technical conference, IAS/PCIC 08-03; 2008.
2. U.S. FCC 1997. Federal Communications Commission 1997. Evaluating compliance with FCC-specified guidelines for human

exposure to radiofrequency radiation. In: U.S. Federal Communications Commission. Office of Engineering and Technology, OET Bulletin 65, Edition 97–101, August 1997, Washington, DC; 1997:67 p. Available from: https://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet65/oet65.pdf.

3. U.S. FCC 2020. U.S. Federal Communications Commission 2020. 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. 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.
4. U.S. FCC 2020. U.S. Federal Communications Commission (FCC) 2020. Federal register, human exposure to radiofrequency electromagnetic fields; correction. A proposed rule by the federal communications commission on 05/04/2020. Available from: https://www.federalregister.gov/documents/2020/05/04/2020-08738/human-exposure-to-radiofrequency-electromagnetic-fields-correction.
5. U.S. FCC 1999. Federal Communications Commission (FCC) 1999. Questions and answers about biological effects and potential hazards of radiofrequency electromagnetic fields. In: U.S. Federal Communications Commission, Office of Engineering and Technology, OET bulletin 56, 4th ed., Washington, D.C.; 1999:3 p. Available from: https://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet56/oet56e4.pdf.
6. Cleveland RF. Human exposure to radiofrequency electromagnetic fields: FCC guidelines; global standards; evaluating compliance; federal and local jurisdiction. 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. Authors Guild backinprint.com Edition, Bloomington, IN: iUniverse, Inc.; 2011: 116–28 pp.
7. NCRP 1986, National Council on Radiation Protection and Measurements (NCRP). Biological effects and exposure criteria for radiofrequency electromagnetic fields, NCRP Report No. 86. Bethesda, MD: Copyright NCRP; 1986.
8. NCRP 1993, National Council on Radiation Protection and Measurements (NCRP). A practical guide to the determination of human exposure to radiofrequency fields, NCRP Report No. 119. Bethesda, MD: Copyright NCRP; 1993. For copies contact: NCRP Publications at: 1-800-229-2652.
9. American National Standards Institute (ANSI). Safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz, ANSI/IEEE C95.1-1992 (previously issued as IEEE C95.1-1991), Copyright 1992. New York, NY, USA: Institute of Electrical and Electronics Engineers, Inc. (IEEE); 1992.
10. The Telecommunications Act of 1996. Public Law 104-104, February 8, 1996, 110 Stat 56, §704(b) ("RADIO FREQUENCY EMISSIONS—within 180 days after the enactment of this Act, the Commission shall complete action in ET Docket 93–62 to prescribe and make effective rules regarding the environmental effects of radio frequency emissions"). The FCC's regulations governing exposure to RF radiation are found at 47 C.F.R. §§1.1307(b), 1.1310. Available from: https://www.congress.gov/104/plaws/publ104/PLAW-104publ104.pdf.
11. 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, 20-1138; 2020. Available from: https://www.nrdc.org/sites/default/files/amicus-brief-fcc-20200805.pdf.
12. Radio Frequency Interagency Work Group (RFIAWG). RF guideline issues identified by members of the federal RF Interagency Work Group, June 1999 Letter to Richard Tell, Chair, IEEE SCC28 (SC4), Risk Assessment Group; 1999. Available from: https://ehtrust.org/wp-content/uploads/2016/04/1999-radiofrequency-interagency-workgroup-letter.pdf.
13. Alster N. Captured agency, how the federal communications commission is dominated by the industries it presumably regulates. Cambridge, MA 02138, USA: Edmond J. Safra Center for Ethics, Harvard University; 2015. Available from: https://creativecommons.org/licenses/by/4.0/ and https://ethics.harvard.edu/files/center-for-ethics/files/capturedagency_alster.pdf.
14. de Lorge JO. Operant behavior and colonic temperature of *Macaca mulatta* exposed to radiofrequency fields at and above resonant frequencies. Bioelectromagnetics 1984;5:233–46.
15. de Lorge J, Ezell CS. Observing-responses of rats exposed to 1.28- and 5.62-GHz microwaves. Bioelectromagnetics 1980;1:183–98.
16. ICNIRP 1998. Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). Oberschleisseim, Germany: International Council on Non-Ionizing Radiation (ICNIRP); 1998.
17. ICNIRP 2010. International Council on Non-Ionizing Radiation. ICNIRP Publication – 2010 ICNIRP Guidelines for limiting exposures to time-varying electric and magnetic fields 1 Hz–100 kHz). Health Phys 2010;99:818–36.
18. ICNIRP 2020. International Commissions on Non-Ionizing Radiation Protection. ICNIRP Guidelines for limiting exposure to electromagnetic fields (100 KHz to 300 GHz), Health Physics; 2020. https://www.icnirp.org/cms/upload/publications/ICNIRPrfgdl2020.pdf [Epub ahead of print].
19. ICNIRP 2020. Differences between the ICNIRP (2020) and previous guidelines: Difference between the 1998 and 2020 RF EMF Guidelines. International Commission on Non-Ionizing Radiation Protection; 2020. Available from: https://www.icnirp.org/en/differences.html.
20. Hardell L, Nilsson M, Koppel T, Carlberg M. Aspects on the International Commission on Non-ionizing Radiation Protection (ICNIRP) 2020 guidelines on radiofrequency radiation. J Canc Sci Clin Ther 2021;5:250–85.
21. 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.
22. U.S. FCC FEDERAL COMMUNICATIONS COMMISSION 47 CFR Parts 1, 2, and 95 [ET Docket No. 03-137; FCC 13-39]. Human Exposure to Radiofrequency Electromagnetic Fields, AGENCY: Federal Communications Commission. ACTION: Final rule. Federal Register/Vol. 78, No. 107/Tuesday, June 4, 2013/Rules and Regulations. Available from: https://www.govinfo.gov/content/pkg/FR-2013-06-04/pdf/2013-12716.pdf.
23. Levitt BB, Lai H. Comments filed, Docket No. 13-89. Before the Federal Communications Commission. In the Matter of Reassessment of Federal Communications Limits and Policies ET Docket No. 13-84, and Proposed Changes in the Commission's Rules Regarding Human Exposure to Radiofrequency

Electromagnetic Fields ET Docket No. 03-137. Sect. 9, Washington, D.C., USA 20554, August 24; 2013:12–3 pp.
24. Sage C, Carpenter DO. Public health implications of wireless technologies. Pathophysiology 2009;16:233–46.
25. BioInitiative Working Group. BioInitiative report: a rationale for a biologically-based public exposure standard for electromagnetic fields (ELF and RF). Report updated: 2014–2020. Sage, C., Carpenter, D.O (eds.); 2012. Available from: www.bioinitiative.org.
26. 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, Chap. 20. Springer International Publishing; 2016:415–42pp.
27. 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, July 14, 2016. 12 pp.
28. Adey WR. Tissue interactions with nonionizing electromagnetic fields. Physiol Rev 1981;61:435–514.
29. Adey WR. Ionic nonequlibrium 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.
30. Adey WR. Nonlinear, nonequlibrium aspects of electromagnetic field interactions at cell membranes. In: Adey WR, Lawrence AF, editors. Nonlinear electrodynamics in biological systems. New York, NY, USA: Plenum Press; 1984:3–22 pp.
31. Gandhi OP. The ANSI radio frequency safety standard: its rationale and some problems. IEEE Eng Med Biol 1987;6:22–5.
32. Frey AH, editor. On the nature of electromagnetic field interactions with biological systems. Austin, TX, USA: R.G. Landes Company; 1994:5–6 pp.
33. 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 International Publishing; 2003:5–33 pp.
34. 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.
35. Panagopoulos DJ. Considering photons as spatially confined wave-packets. In: Reimer A, editor. Horizons in world physics. New York, USA: Nova Science Publishing; 2015, vol 285.
36. Panagopoulos DJ. Man-made electromagnetic radiation is not quantized. In: Reimer A, editor. Horizons in world physics. Nova Science Publishers, Inc; 2018, vol 296. Available from: https://www.researchgate.net/publication/327578880_Man-Made_Electromagnetic_Radiation_Is_Not_Quantized.
37. Peleg M. Biological phenomena are affected by aggregates of many radiofrequency photons. In: International conference on environmental indicators (ISEI), 11 to 14 Sept. 2011 in Haifa. Available from: https://www.researchgate.net/publication/233324730_Bioelectromagnetic_phenomena_are_affected_by_aggregates_of_many_radiofrequency_photons.
38. Peleg M. Thermodynamic perspective on the interaction of radio frequency radiation with living tissue. Int J Biophys 2012;2:1–6.
39. Bruno WJ. What does photon energy tell us about cellphone safety? arXiv preprint arXiv: 1104.5008; 2011. Available from: https://arxiv.org/abs/1104.5008.
40. U.S. FCC 2019, Docket 19-226 FCC 2019. In the Matter of Proposed Changes in the Commission's Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields Reassessment of Federal Communications Commission Radiofrequency Exposure Limits and Policies Targeted Changes to the Commission's Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields, Docket Nos. ET 03-137, 13-84, 19-226, FCC 2019 WL 6681944.
41. U.S. FCC 2020. U.S. Federal Communications Commission (FCC) 2020c. FCC 19-226 comments. https://www.fcc.gov/ecfs/search/filings?proceedings_name=19-226&sort=date_disseminated. DESCcite FCC site.
42. Simkó M, Mattsson MO. 5G wireless communication and health effects – a pragmatic review based on available studies regarding 6 to 100 GHz. Int J Environ Res Publ Health 2019;16:3406.
43. 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.
44. Buchner K, Ravasi M. The International Commission on Non-Ionizing Radiation Protection: conflicts of interest, corporate capture and the push for 5G; 2020. June 2020 Online Report. Available from: https://www.radiationresearch.org/campaigns/the-international-commission-on-non-ionizing-radiation-protection-conflicts-of-interest-corporate-capture-and-the-push-for-5g/.
45. Melnick R. ICNIRP'S evaluation of the National Toxicology Program's carcinogenicity studies on radiofrequency electromagnetic fields. Health Phys 2020;118:678–82.
46. Leszczynski D. New ICNIRP Guidelines… nothing really new… just the same stonewalling. Between a Rock and a Hardplace. Science Blog on Mobile Phone Radiation and Health by Dariusz Leszczynski; 2020. Washington Post, USA, posted online January 23, 2020. Available from: https://betweenrockandhardplace.wordpress.com/2020/01/23/new-icnirp-guidelines-nothing-really-new-just-the-same-stonewalling/.
47. Kim S, Nasim I. Human electromagnetic field exposure in 5G at 28 GHz. IEEE Consumer Electron Mag 2020;9:41–8.
48. World Health Organization. Exposure limits for radio-frequency fields (public): Data by country. Global Health Observatory Data Repository. World Health Organization; 2017. May 31, 2017. Available from: https://apps.who.int/gho/data/view.main.EMFLIMITSPUBCRADIOFREQUENCYv.
49. Microwave News 2020. The lies must stop, disband ICNIRP, facts matter, now more than ever; 2020. Available rom: https://microwavenews.com/news-center/time-clean-house.
50. NRDC. United Keetoowah Band of Cherokee Indians in Okla. V. FCC, 933 F.3d 728 (D.C. Cir. 2019); 2019.
51. Env't Health Tr. v. Fed. Commc'ns Comm'n, No. 20-1025, 2021 WL 3573769, at *1 (D.C. Cir. Aug. 13, 2021); 2021. Available from: https://www.cadc.uscourts.gov/internet/opinions.nsf/FB976465BF00F8BD85258730004EFDF7/$file/20-1025-1910111.pdf.
52. Balmori A. Electromagnetic pollution from phone masts. Effects on wildlife. Pathophysiology 2009;16:191–9.
53. Balmori A. The incidence of electromagnetic pollution on wild mammals: a new "poison" with a slow effect on nature? Environmentalist 2010;30:90–7.

54. Balmori A. Electrosmog and species conservation. Sci Total Environ 2014;496:314–6.
55. Balmori A. Anthropogenic radiofrequency electromagnetic fields as an emerging threat to wildlife orientation. Sci Total Environ 2015;518–519:58–60.
56. Balmori A. Electromagnetic radiation as an emerging driver factor for the decline of insects. Sci Total Environ 2021;767:144913.
57. 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.
58. Magras IN, Xenos TD. RF-induced changes in the prenatal development of mice. Bioelectromagnetics 1997;18:455–61.
59. Nicholls B, Racey PA. Bats avoid radar installations: could electromagnetic fields deter bats from colliding with wind turbines? PLoS One 2007;2:e297.
60. 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.
61. 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.
62. 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.
63. 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;40:393–407.
64. Gandhi O, Riazi A. Absorption of millimeter waves by human beings and its biological implications. IEEE Trans Microw Theor Tech 1986;34:228–35.
65. 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.
66. 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.
67. 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.
68. Marshall TG, Rumann Heil TJ. Electrosmog and autoimmune disease. Immunol Res 2017;65:129–35.
69. Betskii OV, Devyatkov ND, Kislov VV. Low intensity millimeter waves in medicine and biology. Crit Rev Biomed Eng 2000;28: 247–68.
70. Betzkii OV. Use of low-intensity electromagnetic millimeter waves in medicine. Millimetrovie Volni Biol Med 1992;1:5–12 (in Russian).
71. 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.
72. Golant MB. Problem of the resonance action of coherent electromagnetic radiations of the millimetre wave range on living organisms. Biophysics 1989;34:370–82.
73. 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.
74. 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.
75. Hakusui SS. Fixed wireless communications at 60 GHz unique oxygen absorption properties. RF Globalnet, News; 2001. Available from: https://www.rfglobalnet.com/doc/fixedwireless-communications-at-60ghz-unique-0001.
76. Koh C. The benefits of 60 GHz unlicensed wireless communications. Comments filed at FCC; 2004. Available from: https://www.fcc.gov/file/14379/download.
77. Berezhinskii LL, Gridina NI, Dovbeshko GI, Lisitsa MP, Litvinov GS . Visualization of the effects of millimeter radiation on extremely high-frequency electromagnetic radiation on the function blood plasma. Biofizika 1993;38:378–84 (in Russian).
78. Fesenko EE, Gluvstein AY. Changes in the state of water induced by radiofrequency electromagnetic fields. FEBS Lett 1995;367: 53–5.
79. Khizhnyak EP, Ziskin MC. Temperature oscillations in liquid media caused by continuous (nonmodulated) millimeter wavelength electromagnetic irradiation. Bioelectromagnetics 1996;17:223–9.
80. 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).
81. Litvinov GS, Gridina NY, Dovbeshko GI, Berezhinsky LI, Lisitsa MP . Millimeter wave effect on blood plasma solution. Electro-Magnetobiol 1994;13:167–74.
82. Zavizion VA, Kudriashova VA, Khurgin YI. Effect of alpha-amino acids on the interaction of millimeter-wave radiation with water. Millimetrovie Volni Biol Med 1994;3:46–52 (in Russian).
83. Betskii OV, Lebedeva NN. Low-intensity millimeter waves in biology and medicine. Available from: https://stopsmartmetersbc.com/wp-content/uploads/2020/07/Low-intensity-Millimeter-Waves-in-Biology-and-Medicineby-O.V.-Betskii-and-N.N.-Lebedeva-Moscow-Russia-2000.pdf.
84. 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).
85. Michaelson SM, Lin JC. Biological effects and health implications of radiofrequency radiation. New York and London: Plenum Press; 1987:272–7 pp.
86. 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.
87. Thielens A, Greco MK, Verloock L, Martens L, Joseph W. Radiofrequency electromagnetic field exposure of western honey bees. Sci Rep 2020;10:461.

88. Tanner JA. Effect of microwave radiation on birds. Nature 1966; 210:636.
89. Tanner JA, Romero-Sierra C, Davie SJ. Non-thermal effects of microwave radiation on birds. Nature 1967;216:1139.
90. 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-visionis-sharp/#.WlU2d3lG3Z4.
91. Endangered Species Act (ESA) of 1973 (16 U.S.C. 1531 et seq.). Available from: https://www.fws.gov/endangered/esa-library/pdf/ESAall.pdf and https://www.fws.gov/endangered/laws-policies/esa.html.
92. Endangered Species Act (ESA) of 1973 (16 U.S.C. 1531 et seq). Revisions available from: https://www.fws.gov/endangered/improving_ESA/regulation-revisions.html.
93. Convention on international trade in endangered species of wild fauna and flora (CITES 1973). Available from: https://www.fws.gov/international/cites.
94. Endangered species act (ESA) of 1973, section 4(b)3(A), candidate species. Available from: https://www.fws.gov/endangered///laws-policies/section-4.html.
95. U.S. Fish and Wildlife Service. Engendered species. Available from: https://www.fws.gov/endangered/.
96. U.S. National oceanic and atmospheric Administration's (NOAA) national marine fisheries service (NMFS). Available from: www.fisheries.noaa.gov/laws-and-policies/glossary-end.
97. Endangered Species Act (ESA97) of 1973. Section 7: Interagency Cooperation. Available from: https://www.fws.gov/midwest/Endangered/section7/section7.html and Endangered Species Act (ESA) of 1973. Interagency Cooperation U.S.C. S. 1536(a)(2). Available from: https://uscode.house.gov/view.xhtml?path=%2Fprelim%40title16%2Fchapter35&edition=prelim.
98. Endangered Species Act (ESA) of 1973. Section 10: exceptions. Available from: https://www.fws.gov/endangered/laws-policies/section-10.html.
99. Endangered Species Act (ESA) of 1973. List of endangered and threatened species. Available from: https://ecos.fws.gov/ecp0/reports/ad-hoc-species-report?kingdom=V&kingdom=I&status=E&status=T&status=EmE&status=EmT&status=EXPE&status=EXPN&status=SAE&status=SAT&mapstatus=3&fcrithab=on&fstatus=on&fspecrule=on&finvpop=on&fgroup=on&header=Listed+Animals.
100. The California Biologists Handbook 2021. Section 10 ESA – HCP process. Available from: https://biologistshandbook.com/permits/federal-permits/section-10-consultation-federal-esa.
101. Endangered Species Act (ESA) of 1973. Section 11 penalties and enforcement. Available from: https://www.fws.gov/endangered/laws-policies/section-11.html.
102. Endangered Species Act (ESAd) of 1973. U.S. Department of Justice. Implementation of ESA and related litigation. Available from: https://www.justice.gov/enrd/endangered-species-act.
103. Migratory Bird Treaty Act of 1918 (16. U.S.C. 703-712, MBTA). Available from: https://www.fws.gov/birds/policies-and-regulations/laws-legislations/migratory-bird-treaty-act.php?mod=article_inline.
104. Code of Federal Regulations (50 C.F.R. 10.13 list). List of Endangered, threatened and species of special concern. Gpo.gov e-CFR Navigation aids. Current May 28, 2021. Available from: https://www.ecfr.gov/cgi-bin/text-idx?SID=b85587342ebe4f607983dfb6d1e07461&mc=true&node=se50.1.10_113&rgn=div8.
105. Endangered Species Act (ESA) of 1973. Birds: Available from: https://www.fws.gov/birds/bird-enthusiasts/threats-to-birds.php and http://www.fws.gov/migratorybirds/.
106. United States Department of the Interior 2021. Letter and Memorandum regarding: M-37065, To: Secretary Assistant Secretary – Fish and Wildlife and Parks, From: Principal Deputy Solicitor. Subject: Permanent Withdrawal of Solicitor Opinion M-37050 "The Migratory Bird Treaty Act Does Not Prohibit Incidental Take". Washington, D.C: Office of the Solicitor. March 8, 2021. Available from: https://www.doi.gov/sites/doi.gov/files/permanent-withdrawl-of-sol-m-37050-mbta-3.8.2021.pdf.
107. U.S. Fish and Wildlife Service. Birds of Conservation Concern (BCC). Arlington, Virginia: United States Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management; 2008:85 p. Available from: https://www.fws.gov/migratorybirds/pdf/grants/BirdsofConservationConcern2008.pdf.
108. U.S. Fish and Wildlife Service. Fish and Wildlife Conservation Act (16 U.S.C. 2901-2912). Available from: https://www.fws.gov/laws/lawsdigest/FWCON.HTML.
109. Manville AM, II. Anthropogenic-related bird mortality focusing on steps to address human-caused problems. A white paper for the Anthropogenic Panel. In: 5th International Partners in Flight Conference, August 27, 2013. Utah: Snowbird; 2013:16 p.
110. Manville AM. Status of U.S. Fish and Wildlife Service developments with communication towers with a focus on migratory birds: updates to Service staff involved with tower issues. In: Webinar summary talking points 2014:14 p.
111. Migratory Bird Executive Order 13186, Responsibilities of Federal Agencies to Protect Migratory Birds; 2001. Available from: https://www.federalregister.gov/documents/2001/01/17/01-1387/responsibilities-of-federal-agencies-to-protect-migratory-birds.
112. The Bald and Golden Eagle Protection Act (BGEPA) (50 C.F.R. 22., 22.26 and 22.27). Available from: https://www.fws.gov/southeast/our-services/permits/eagles/.
113. Eagle Conservation Plan Guidance. Module 1 – Land-based Wind Energy Version 2. U.S. Fish and Wildlife Service. Division of Migratory Bird Management; 2013. Available from: https://fws.gov/migratorybirds/pdf/management/eagleconservationplanguidance.pdf.
114. The National Environmental Policy Act (NEPA) 42 U.S.C. §4321 et seq. 1969. Available from: https://www.epa.gov/laws-regulations/summary-national-environmental-policy-act.
115. The National Environmental Policy Act of 1970. Available from: https://en.wikipedia.org/wiki/National_Environmental_Policy_Act.
116. Categorical exclusions 40 C.F.R. §1508.4. Available from: https://www.govinfo.gov/app/details/CFR-2010-title40-vol32/CFR-2010-title40-vol32-sec1508-4 and https://www.law.cornell.edu/cfr/text/40/1508.4. 115 p.
117. U.S. FCC. U.S. Federal Communications Commission 2019a. Accelerating Wireless Broadband Deployment by Removing Barriers to Infrastructure Investment, FCC 18-30, WT Docket No. 17-79. A Rule by the Federal Communications Commission on 11/05/2019. The Federal Register; 2019. Available from: https://www.federalregister.gov/documents/2019/11/05/2019-24071/accelerating-wireless-broadband-deployment-by-removing-barriers-to-infrastructure-investment.

118. Montgomery County v. FCC et al. Case: 19-70123, 06/10/2019, ID: 11325914; 2019. Reply brief available from: https://www.montgomerycountymd.gov/cable/Resources/Files/Towers/ZTAFiles/Mont%20Co%20Reply%20Brief%20(RF%20emissions).pdf.
119. H.R. 6488 (116th). Streamlining Permitting to Enable Efficient Deployment of Broadband Infrastructure Act of 2020. Available from: https://www.congress.gov/bill/116th-congress/house-bill/6488?s=1&r=3.
120. Species at Risk Act (SARA S.C. 2002, c. 29). Available from: https://laws-lois.justice.gc.ca/eng/acts/s-15.3/.
121. Species at Risk Act (SARA S.C. 2002, c. 29). List of Wildlife Species at Risk. Available from: https://laws-lois.justice.gc.ca/eng/acts/s-15.3/page-17.html#h-435647.
122. Species at Risk Act (SARA S.C. 2002, c. 29). Critical Habitat. Available from: https://laws-lois.justice.gc.ca/eng/acts/s-15.3/.
123. Species at Risk Act (SARA S.C. 2002, c.29) Recovery of Endangered, Threatened and Extirpated Species. Available from: https://laws-lois.justice.gc.ca/eng/acts/s-15.3/page-5.html#h-434811.
124. Environment and Climate Change Canada – Canada. Available from: https://www.canada.ca/en/environment-climate-change.html.
125. Migratory Birds Convention Act (MBCA) 1994 (S.C. 1994, c. 22). Available from: https://laws-lois.justice.gc.ca/eng/acts/m-7.01/.
126. Migratory Birds Regulations (C.R.C., c. 1035) Available from: https://laws-lois.justice.gc.ca/eng/regulations/C.R.C.%2C_c._1035/index.html.
127. UN Convention on Biodiversity 2021. Available from: https://www.un.org/en/observances/biological-diversity-day/convention.
128. Migratory Birds Convention as amended under the 1995 Protocol. Available from: https://www.canada.ca/en/environment-climate-change/services/migratory-birds-legal-protection/convention-act.html.
129. Chesser RT, Billerman SM, Burns KJ, Cicero C, Dunn JL, Kratter AW, et al. Check-list of North American Birds (online). American Ornithological Society; 2020. Available from: http://checklist.aou.org/taxa.
130. European Commission 2020. Nature and Biodiversity Law. Available from: https://ec.europa.eu/environment/nature/legislation/index_en.htm.
131. European Commission 2020. Birds Directive. Available from: https://ec.europa.eu/environment/nature/legislation/birdsdirective/.
132. European Commission 2021. Progress in the implementation of the EU Pollinators Initiative 2021. Report from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions. Brussels, 27.5.2021 COM(2021) 261 final. Available from: https://ec.europa.eu/environment/pdf/nature/conservation/species/pollinators/Progress_in_the_implementation_of_the_EU_Pollinators_Initiative.pdf.
133. Carter E. Birding in the United States: demographic and economic analyses. Arlington, VA: U.S. Fish and Wildlife Service Report 2011-1; 2013:16 p.
134. Kunz TH, Gauthreaux SA Jr., Hristov NI, Horn JW, Jones G, Kalko EKV, et al. Aeroecology: probling and modeling the aerospace. Integr Comp Biol 2008;48:1–11.
135. Manville AM, II. Recommended lighting standards and lighting protocols for structures requiring pilot warning lighting, and for security lighting purposes. Peer-reviewed report. Div. Mgt. Bird Mgt., USFWS; 2013:6 p.
136. Manville AM, II. Comments of the U.S. Fish and wildlife service submitted electronically to the FCC on 47 CFR parts 1 and 17, WT docket No. 03-187, FCC 06-164, notice of proposed rulemaking. Effects of Communication Towers on Migratory Birds. February 2, 2007; 2007:32 p.
137. Manville AM. Status of U.S. Fish and Wildlife Service developments with communication towers with a focus on migratory birds: updates to Service staff involved with tower issues. A Webinar. Talking points and literature citations; 2014: 13 p. Available to the Public [Released to the public March 7, 2014.
138. Longcore T, Rich CP, Mineau PB, MacDonald B, Bert DG, Sullivan LM, et al. An estimate of avian mortality at communication towers in the United States and Canada. PLoS One 2012;7:e34025.
139. Electromagnetic Radiation Safety. Dept. of Interior attacks FCC regarding impact of cell tower radiation on wildlife. Press release; 2014:2 p. March 24, 2014.
140. Department of Interior. Letter from W.R. Taylor, Director, Office of Environmental Policy and Compliance to E. Veenendaal, National Telecommunications and Information Administration, U.S. Department of Commerce, ER 14/0001) (ER 14/0004), Feb. 7, 2014; 2014:8 p. Available from: https://ecfsapi.fcc.gov/file/1070795887708/Department%20of%20Interior%20Feb%202014%20letter%20on%20Birds%20and%20RF.pdf.
141. Manville AM, II. U.S. Fish and wildlife service involvement with towers, turbines, power lines, buildings, bridges and MBTA E.O. 13186 MOUs – lessons learned and next steps. In: Migratory Bird Treaty Act Meeting – a workshop held in the Washington Fish and Wildlife Office. Lacey, WA. March 20, 2009, 32 PowerPoint slides; 2009.
142. Manville AM, II. Towers, turbines, power lines and buildings – steps being taken by the U.S. Fish and Wildlife Service to avoid or minimize take of migratory birds at these structures. In: Rich TD, Arizmendi C, Demarest DW, Thompson C, editors. Tundra to tropics: connecting birds, habitats and people. Proceedings 4th international partners in flight conference, Texas. McAllen; 2009:262–72 pp.
143. Smallwood KS. Comparing bird and bat fatality-rate estimates among North American wind-energy projects. Wildl Soc Bull 2013:37:19–33.
144. Loss SR, Will T, Marra PP. Refining estimates of bird collision and electrocution mortality at power lines in the United States. PLoS One 2014;9:e101565.
145. Loss SR, Will T, Marra PP. The impact of free ranging domestic cats on wildlife in the United States. Nat Commun 2013;4:1396.
146. Klem D, Jr. Avian mortality at windows: the second largest human source of mortality on earth. In: Rich TD, Arizmendi C, Demarest DW, Thompson C, editors. Tundra to tropics: connecting birds, habitats and people. Proceedings 4th international partners in flight conference, Texas. McAllen; 2009:244–54 pp.
147. Klem D, Jr, Saenger PG. Evaluating the effectiveness of select visual signals to prevent bird-window collisions. Wilson J Ornithol 2013;125:406–11.
148. Frick W, Chilson P, Fuller N, Bridge E, Kunz T. Aeroecology. In: Adams RA, Pedersen SC, editors. Bat evolution, ecology, and conservation. New York: Springer Science+Business Media; 2013.

149. Hristov NI, Betke M, Kunz TH. Applications of thermal infrared imaging for research in aeroecology. Integr Comp Biol 2008;48: 50–9.
150. Horn JW, Kunz TH. Analyzing NEXRAD Doppler radar images to assess nightly dispersal patterns and population trends in Brazilian free-tailed bats (*Tadarida basiliensis*). Integr Comp Biol 2008;48:24–39.
151. 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, March 2002; 2002:9 p.
152. Tanner JA, Romero-Sierra C. Biological effects of nonionizing radiation: an outline of fundamental laws. Ann N Y Acad Sci 1974;238:263–72.
153. Thielens A. Environmental impacts of 5G: a literature review of effects of radio-frequency electromagnetic field exposure of non-human vertebrates, invertebrates and plants. Panel for the Future of Science and Technology (STOA). European Parliament; 2021:137 p. PE 690.021.
154. National Climate Assessment 2014, Melillo JM, Richmond TC, Yohe GW, editors. Out Changing Climate: Climate Change Impacts in the United States: The Third National Climate Change Assessment. U.S. Global Change Research Program 19-67. GlobalChange.gov. National Academy of Sciences.
155. 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.
156. Hakusui SS. Fixed wireless communications at 60 GHz unique oxygen absorption properties. RF Globalnet, News; 2001. https://www.rfglobalnet.com/doc/fixed-wireless-communications-at-60ghz-unique-0001.
157. Helliwell RA. Whistlers and related ionospheric phenomena. Mineola, NY, USA: Dover Publications; 1965.
158. Lorenz EN. Deterministic nonperiodic flow. J Atmos Sci 1963;20: 130–41.
159. Lorenz EN. The predictability of hydrodynamic flow. Trans N Y Acad Sci 1963;25:409–32.
160. Lorenz EN. Predictability. In: AAAS 139th meeting, Washington, DC, USA; 1972.
161. Marino A. Assessing health risks of cell towers. 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. Authors Guild backinprint.com Edition. Bloomington, IN: iUniverse, Inc.; 2011:87–103 pp.