Environmental Evidence

SYSTEMATIC MAP PROTOCOL

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What evidence exists on the impact of anthropogenic radiofrequency electromagnetic fields on animals and plants in the environment? A systematic map protocol

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Abstract

Background: Exposure to radiofrequency (RF) electromagnetic fields (EMF), particularly from telecommunications sources, is one of the most common and fastest growing anthropogenic factors on the environment. In many countries, humans are protected from excessive RF EMF exposure by safety standards that are based on guidelines by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The ICNIRP guidelines are based on knowledge of how RF EMF affects the human body, however, there are currently no recognised international guidelines to specifically protect animals and plants. Whether the ICNIRP guidelines for humans is adequate to provide protection to the environment is a subject of active debate. This systematic map will collate all the available evidence on whether anthropogenic RF EMF has a negative effect on plants and animals in the environment. The map will also identify gaps in knowledge, recommend future research and inform environmental and radiation protection authorities.

Methods: The proposed systematic map will include peer-reviewed and grey literature published in English. The EMF—Portal, PubMed and Web of Science databases will be searched using a search string prepared by the review team and tested for comprehensiveness against a list of known relevant reviews. Once duplicates are removed, retrieved articles will be screened in three stages: title, abstract, and full text. Studies will be selected with a subject population of all plants and animals, with exposures to anthropogenic RF EMF (frequency range 100 kHz–300 GHz) compared to no or lower-level exposure, and for all outcomes related to the studied populations. Kappa statistic tests will be conducted at each stage to ensure consistency of decision-making regarding the predefined inclusion/exclusion criteria. Eligible studies will then proceed to the data extraction phase, which will extract meta-data such as bibliographic information, taxonomic information, RF EMF exposure data, outcome(s), sample size, etc. The extracted data will then be organised into a systematic map and the findings summarised by cross-tabulating key meta-data variables in heat maps, charts or other data visualization methods. The systematic map will identify gaps in knowledge, priorities for future research and potential subtopics for further analysis and/or systematic review.

Keywords: Anthropogenic radiofrequency electromagnetic fields, Base stations, 5G, Broadcast towers, Radar, Telecommunication, Plants, Animals, Environment

Background

Exposure to radiofrequency (RF) electromagnetic fields (EMF) is one of the most common and fastest growing anthropogenic factors on the environment [1]. Although

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RF EMF is part of nature (emitted by sources like the sun, the earth and the ionosphere), technological advancements over the last century have made artificial sources the main contributor of RF EMF exposure in the environment [2]. Artificial sources of RF EMF are mainly used for telecommunications purposes such as radio and television broadcasting, mobile telephony, satellite transmissions, Wi-Fi and numerous other wireless communications [2]. Other uses of RF EMF include security and navigation (e.g. RF identification and radar), industrial applications (e.g. heating and welding) and agricultural uses (e.g. insect control and product processing) [2, 3]. The global pervasiveness of these sources, particularly for telecommunications, means that anthropogenic RF EMF is ubiquitous in the environment [4]. In a world with ever-advancing technology it is anticipated that sources of RF EMF will increase and there is some concern of potential adverse effects which are not fully alleviated by existing scientific data [1]. Public concern on the health implications of telecommunications sources has been a long-standing issue but has intensified during the current roll-out of the 5G mobile phone network [5]. The public outcry regarding the development of the 5G network has taken the form of anti-5G groups, petitions to governments and numerous protests around the world [6]. Apart from possible effects on human health, there is also public concern that 5G and other telecommunications sources may affect the natural terrestrial and aquatic environment since animals and plants have natural responses to specific types of EMF, including migratory patterns and pollination [7].

RF EMF is physically defined as the transfer of energy (or radiation) by radio waves in the frequency range between 100 kilohertz (kHz) to 300 gigahertz (GHz) [2]. Different sources of RF EMF operate at distinct frequency bands across the RF range. In telecommunications, for example, AM radio operates between 100 and 3000 kHz; FM radio and VHF television between 30 megahertz (MHz) to 300 MHz; and UHF television and 3G/4G mobile telephone networks between 300 MHz and 3 GHz [8]. The 5G network currently operates at 3.6 GHz and 26–28 GHz and there are plans for future mobile networks to utilise higher frequency bands beyond 60 GHz [9]. The intensity of RF EMF exposure is dependent on the power level of the source and is expressed as the strength of either the electric or magnetic field component, in units of 'volts per metre' (V/m) or 'amperes per metre' (A/m), respectively [2]. Another common measure used to express the intensity of RF EMF is the power density in units of watts per square metre (W/m^2) and these measures are inter-linked. The intensity of RF EMF decreases very rapidly with distance so although there are many sources in the environment, it is close proximity to a particular source (e.g. next to a radio broadcast antenna) that typically dominates the exposure [2].

RF EMF is classified as non-ionising radiation, and unlike ionising radiation, it does not carry enough energy to ionise atoms or molecules (i.e. remove electrons from their orbit) which can change the chemical composition of material [2]. Non-ionising radiation has less energy but can still excite molecules and atoms causing them to vibrate faster [10]. The interaction of RF EMF exposure with biological material is dependent on a number of factors including the frequency, the intensity and the duration of the exposure, as well as the size and shape of the receiving material and its composition in terms of its susceptibility to EMF (often called dielectric characteristics) [11]. When a biological entity is exposed to RF EMF some of the energy is reflected away and some is absorbed by the entity. RF fields become less penetrating into biological tissue with increasing frequency and for frequencies above 6 GHz the depth of penetration is relatively short and is contained superficially on the surface of the biological material [12]. The RF energy that is absorbed in biological material, expressed by the specific absorption rate in units of watts per kilogram (W/kg), causes movement of molecules and electrically charged particles, which in turn creates heat [13]. Exposure to sufficiently high levels of RF EMF can excessively heat biological tissue and potentially cause tissue damage; this is often referred to as the 'thermal effect' of RF EMF. Exposure to RF EMF also induces electric fields within the body and at frequencies below about 10 MHz high exposure levels can stimulate excitable tissue such as nerves and muscle [11].

In order to protect humans from excessive exposure to RF EMF, international guidelines have been developed that recommend limits on exposure to RF fields [13, 14]. The guidelines developed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), in particular, form the basis for regulating exposure to RF EMF in many countries [15]. Exposure to RF EMF in the environment from various (mainly telecommunications) sources is generally low and much lower than the ICNIRP safety limits [16, 17]. Exposure exceeding the ICNIRP limits can occur adjacent to some sources such as mobile phone base stations, broadcast antennas and radar [4]. These areas are generally not accessible to people but may be entered by animals such as birds and insects. It should be noted that the ICNIRP guidelines are based on knowledge of RF absorption on the human body, for example, relating to mechanisms of thermoregulation on human core body temperature [13]. Animals such as insects and certain types of plant structures lack an inner means for thermoregulation and have evolved other strategies to withstand exposure to heat, including from RF fields

exceeding the ICNIRP limits [18, 19]. Despite this, there are currently no recognised international guidelines to specifically protect animals and plants.

Notwithstanding the large body of research underpinning the existing exposure limits in the ICNIRP guidelines, the issue of whether they are adequate to provide complete protection to both humans and to the environment from harmful effects of exposure to RF EMF remains a subject of research and active debate within the scientific and wider community [20]. Thousands of studies have been published in the last few decades reporting on whether the low-level exposure encountered in the environment, mainly from telecommunications sources, is harmful to humans. Although many studies have reported possible low-level effects for humans, results are, in general, inconsistent and lack a clear biophysical mechanism of interaction. Several expert panels have reviewed this body of evidence, generally agreeing that there is no substantiated evidence that low-level RF EMF is harmful to human health [4, 13, 21, 22]. However, there are gaps in the knowledge and the World Health Organization is currently conducting a series of systematic reviews investigating the effects of RF EMF on a number of outcomes related to human health [1].

A relatively smaller number of studies and reviews have been published on the impact of anthropogenic RF EMF on animals and plants in the environment. Cucurachi et al. (2013) conducted a systematic review on the potential environmental effects of RF EMF using older guidelines for systematic review [23, 24]. Since then, newer guidelines on performing a systematic review have been developed that have improved the search and selection of studies, the assessment of study validity and the synthesis of results. The latest guidelines prescribed by the Collaboration for Environmental Evidence (CEE), in particular, are specific for the systematic synthesis of evidence related to the environment [25]. The Cucurachi review included 113 studies on insects, birds, other vertebrates and plants. It found mixed results that were species-dependent across various biological end-points including reproduction, growth, behaviour, mutation and population decline. The majority of studies were conducted in the laboratory and there was large heterogeneity across the exposure conditions and the quality of the methods employed. The review found a limited number of observational studies investigating real-life RF exposure which were largely hampered by the inadequate treatment of confounding factors such as other anthropogenic exposures. Although a number of the studies reported effects at low levels of RF EMF, no clear relationship was determined between effects found in different studies and the level of RF exposure. Apart from the methodology being dated, the Cucurachi review only included studies with an RF exposure frequency range between 10 MHz and 3.6 GHz, largely because telecommunications sources operated within this frequency range at the time. However newer technologies, such as the 5G mobile phone network, now operate at higher frequencies and a review of the research should encompass the entire RF range.

A number of more recent reviews on anthropogenic RF EMF exposure have assessed the evidence on specific environmental topics e.g. animal orientation and migration [26], effects on insect pollinators [27], and alterations in the morphology and development of plants [28]. However, these reviews have generally been narrative rather than systematic, lacking detailed literature search methods or a rationale for the inclusion or exclusion of relevant studies. The inclusion of studies has often been selective (e.g. only presenting studies that show an effect) and a detailed analysis of the included studies has often been lacking. The European Union Eklipse project, which provides advice on issues related to biodiversity, published a recent overview on the impact of EMF on animals and plants [29]. Eklipse noted that the majority of the reviews are not systematic or objective but appear to be unbalanced and asserting a particular world view (i.e. that anthropogenic EMF is a problem for biodiversity) without strong supporting evidence.

There is a great need for a systematic collation of all the available evidence on whether anthropogenic RF EMF has a negative impact on animals and plants in the environment. This is particularly timely given the public concern over the impact of the 5G network and other telecommunications sources on the environment. Currently, policies on RF exposure, particularly from telecommunications, are driven principally by issues associated with human safety. Awareness of any environmental impacts of RF EMF is therefore important to also ensure the protection of animals and plants. Previous reviews as described earlier have identified a wide range of environmental topics on animals and plants with numerous outcomes, and it is therefore appropriate to first conduct a systematic map of the evidence. This can be followed by systematic reviews on specific topics. This systematic map will collate all the available evidence on the impact of RF EMF on animals and plants using the latest guidelines for systematic synthesis of data prescribed by the Collaboration for Environmental Evidence [25]. It will also identify gaps in knowledge, recommend future research and inform environmental and radiation protection authorities on the safety of animals and plants in the face of global increases in the use of RF EMF.

Stakeholder engagement

The current systematic map will be conducted by the Australian Radiation Protection and Nuclear Safety

Agency (ARPANSA) in collaboration with Swinburne University of Technology. ARPANSA is the Australian Government's primary authority on protecting people and the environment from the harmful effects of radiation [30]. Swinburne University of Technology has a long history of conducting research into the effects of RF EMF, including specific investigations into the effects on animals and plants [31]. The systematic map will be conducted as part of the Australian Government's Electromagnetic Energy (EME) Program [32], which aims to promote the health and safety of humans and the environment from existing and new telecommunications technologies like 5G.

The Australian Government sought input from relevant stakeholders on the impact of RF EMF on people and the environment in an *Inquiry into 5G in Australia* [33]. Various community groups and members of the public expressed concern on the impact of RF EMF on animals and plants, citing the lack of research on this issue. Similar input was also received in a public consultation conducted by ARPANSA on a draft safety standard for RF EMF exposure [7].

We consulted with academic experts in the area of RF bioeffects to assist in the formulation of the main and secondary questions and then define the scope of the systematic map. We will continue to engage with experts as well as other relevant stakeholders including industry, government and non-government organisations throughout the development of the systematic map. Specifically, input into the progress of the map will be regularly sought through the Australian Government's EME Working Group, which meets monthly and includes ARPANSA and other government departments. We will also provide the opportunity for the EME Working Group and other stakeholders to review the final map. The final systematic map will be provided to environmental and radiation protection authorities.

Objective of the systematic map

The objective of this systematic map is to identify, collate and categorise all relevant evidence on the impact of anthropogenic RF EMF exposure on animals and plants in the environment. This will include peer reviewed literature as well as academic grey literature. We will include studies performed in situ (natural environment) and ex situ (laboratory, cage, aquarium etc.) that have investigated any outcome related to the impact on animals and plants in the environment. The systematic map will cover all kinds of impacts from biological to ecological. We will identify factors that may contribute to possible impacts, including types of studies (e.g. experimental/observational, in situ/ex situ), RF EMF exposure characteristics (e.g. RF frequency, intensity, duration) and taxonomic groups (e.g. animals/plants, class, species). We will specifically identify whether the exposure in studies was below or above the safety limits to protect humans which is important in assessing whether international standards can also protect animals and plants. We will also identify whether studies investigating the impact of RF EMF exposure have accounted for other covariates such as other environmental/anthropogenic factors that may be related to the investigated outcome. Based on these factors the systematic map will identify subtopics and describe the quantity of evidence available on each subtopic. Finally, the systematic map will ascertain gaps in the evidence, priorities for future research and potential subtopics for further analyses and/or systematic reviews.

Primary question

What research has been conducted to assess the impact of anthropogenic RF EMF exposure on animals and plants in the environment?

Secondary questions

- Which species, kinds of impacts and types/sources of RF EMF have been studied?
- What information is available on whether impacts are species-dependent and/or dependent on RF EMF exposure characteristics?
- What information is available on whether exposure protection standards for humans also protect animals and plants?
- Have studies investigating the impact of RF EMF exposure accounted for other covariates such other environmental/anthropogenic factors?
- What are the gaps in the evidence that could/should be addressed by future research?
- Which particular subtopics could be addressed by further analysis or specific systematic reviews?

Components of the systematic map

The components of the systematic map are shown in Table 1. Detailed descriptions of each component are provided in Article screening and study eligibility criteria.

Methods

Searching for articles

The search strategy has been designed to identify a comprehensive set of research papers investigating RF EMF exposure from a wide range of sources on animals and plants. The systematic map follows CEE guidelines and the ROSES reporting standard (see Additional file 1 for checklist of ROSES guidelines) [25, 34].

Table 1 Components of the systematic map

Population (P)	All animals and plants
Exposure (E)	Anthropogenic RF EMF in the frequency range 100 kHz–300 GHz
Comparator (C)	Sham-exposure, no or lower-level exposure
Outcome (O)	All outcomes related to the studied population, including but not limited to biological/physiological endpoints, growth/development, behaviour and population abundance/decline

Search terms and languages

The systematic map will only include studies published in English due to limitations in the languages understood by the research team and resource limitations in obtaining translations. As such, searches will be conducted using English search terms only. Search terms describing the exposure (RF EMF) and the population (animals and plants) were combined to efficiently find relevant studies. These search terms were selected from previous reviews and the review team's knowledge in this field of research [12, 21, 24, 27, 29]. Outcome terms were not included in the search as this would compromise the aim of the systematic map by restricting the effects documented in the research articles. The full list of search terms is detailed below.

Search strings

A scoping exercise was conducted to test numerous search strings. The search terms that will be used are:

Exposure: 2G, 3G, 4G, 5G, antenna, base station, CDMA, cell phone, cell tower, cellular network, cellular tower, electric field, electromagnetic, electrosmog, EME, EMF, EMR, GHz, gigahertz, GSM, handy, hertz, Hz, intermediate frequency, kHz, kilohertz, LTE, megahertz, MF, MHz, microwave, millimetre, MMW, mobile network, mobile phone, mobile tower, non-ionising, radar, radio, radiofrequency, RF, smart meter, telecommunication, telephony, television, terahertz, THz, TV, UMTS, WDCMA, wi fi, wireless.

Population: amoeba, amphibian, angiosperm, animal, arthropod, bat, bee, biodiversity, biota, birds, bug, cat, cereal, colony, cow, crop, dog, drosophila, ecology, ecosystem, environment, fauna, fish, flora, flower, insect, invertebrate, maize, mammal, marine, moss, pigeon, plant, pollinator, rice, seed, species, spore, tree, vertebrate, wildlife.

When permissible with the database, search terms within the 'exposure' and 'population' categories will be combined using the Boolean operator 'OR'. The Boolean operator 'AND' will then be used to combine these 2 categories. When necessary, search terms will be written with a wildcard at the end to include alternate forms of the word. The final Boolean search strings can be found in Additional file 2. The search will be conducted to find articles that have an exposure and population term in the title of the article. There will be no timeframe restriction on articles accepted.

Comprehensiveness of the search

The comprehensiveness of the search string was assessed by testing whether reviews of known relevance were found when conducting searches of the EMF Portal, PubMed and Web of Science databases. A list of 40 articles including 23 reviews of known relevance and 17 primary studies were chosen and used to test the search string. Reviews that were not initially retrieved were assessed and the search string was modified to add search terms or wildcards to improve the comprehensiveness of the search. The final search string found all 40 reviews (100%) across the 3 databases (see Additional file 3). As all articles were retrieved with modification of the search string, it was concluded that the comprehensiveness of the search strategy is sufficient. The final Boolean search strings are available in Additional file 2.

Publication databases

The EMF Portal, PubMed and Web of Science databases were chosen for finding articles in the systematic map. This was based on the criteria that they covered the exposures and populations, were reproduceable, and the review team had access to them. Due to resource limitations, no further databases were considered given the number of articles found during the comprehensiveness of search scoping exercise.

The EMF Portal is an internet platform produced by RWTH Aachen University (https://www.emf-portal.org/en). It has collected an extensive literature database of 34,372 publications on the effects of electromagnetic fields with articles dating back as far as 1904. As this database is specific to EMF exposure, when conducting the search only the population search terms will be used along with filters for topics and frequency range. The filters selected for topics will be 'Experimental studies'; 'Epidemiological studies'; 'Reviews, surveys, summaries'; 'Other'. The filters selected for frequency ranges will be 'Radio frequency'; 'Mobile communications'. This was the search strategy used for the EMF Portal component of the comprehensiveness of search test which was

conducted on the 10th of November 2021 and found 3397 articles.

The PubMed database was selected due to its open access and comprehensive database on biomedical and life sciences literature (https://pubmed.ncbi.nlm.nih.gov/). This database has over 30 million articles from 1966 to the present, with further selective articles from 1809. The comprehensiveness of search test using the Boolean search string supplied in Additional file 2 found a total of 4345 articles.

The Web of Science (Clarivate) was accessed via the review team members institutions. The Science Citation Index Expanded (SCI-EXPANDED; 1900 to present), Conference Proceedings Citations Index-Science (CPCI-S; 1990 to present and Emerging Sources Citation Index (ESCI; 2005 to present) databases were selected from the Web of Science Core Collection to conduct the search. These databases were selected as they were most relevant for the topic and included grey literature published as part of conference proceedings. As part of the comprehensiveness of search test, 18,540 articles were found using the Boolean search string supplied in Additional file 2. Of these, 7,272 articles were conference proceedings papers and 554 were meeting abstracts demonstrating an extensive collection of grey literature.

Supplementary searches

To improve the comprehensiveness of our searches, the bibliographies of relevant articles and reviews found will also be searched for further papers (i.e., backward citation chasing). Additionally, articles that cite retrieved relevant articles will also be searched for further papers using Web of Science (via Cited Reference Search option) and Google Scholar (i.e., forward citation chasing). Members of the review team will also use their professional networks and knowledge to identify relevant studies.

Article screening and study eligibility criteria

Screening process

The retrieved articles from the database searches will be uploaded to EndNote 20 for screening. Prior to screening, duplicates will be removed as well as articles not in English using EndNote functions. Articles will be screened in three stages: title, abstract, and full text.

First stage

In the first stage articles will first be screened based on titles alone by a single reviewer. In the cases of uncertainty or if there is insufficient information to make an informed decision, the reviewer will include the articles for the next stage of screening. To test for consistency of decision-making regarding inclusion/exclusion a subset of 100 or more studies will be randomly selected and assessed by two reviewers. A kappa statistic will be produced to assess interrater reliability and if reviewers are found to be inconsistent (kappa rating < 0.6) the inclusion/exclusion criteria will be clarified and or modified. The test for consistency of decision-making will be repeated with a new sub-set of studies until a kappa rating of 0.6 or greater is achieved.

Second stage

Articles that pass the first stage of screening will then be screened in the second stage based on abstract, where the same process as the first stage will be repeated.

Third stage

Finally, in the third stage the full text of the articles will be reviewed by a single reviewer for articles included after the abstract stage of screening. The full texts will be retrieved using author affiliation licenses. Any full texts that are unavailable will be sourced from Google Scholar or will be requested from the authors. Any articles that are uncertain for inclusion will be reviewed by the team. Similarly, a subset of 100 articles will be assessed by 2 reviewers and a kappa statistic produced. If reviewers are found to be inconsistent (kappa rating < 0.6) the inclusion/exclusion criteria will be clarified and or modified. The test for consistency of decision-making will be repeated with a new sub-set of studies until a kappa rating of 0.6 or greater is achieved.

Studies or datasets found by bibliographic searches or other means will be added at the second stage of the screening process. Eligible studies will then proceed to the data extraction phase.

Search update

A search update will be performed prior to the completion of the systematic map database. The search strategy will be repeated to find articles published in the time period after the original searches were conducted. New search results will be screened in the same way as the original search results.

Eligibility criteria

Article eligibility will be based on the following inclusion/exclusion criteria:

Eligible populations or subjects

Any species of non-human animals and plants. We will exclude rats, mice and guinea pigs, which have been used in laboratory studies as surrogate animal models for research related to human health; but will include these animals in studies investigating them in situ in their natural environment. We will also exclude micro-organisms such as fungi and bacteria because they are just as

relevant to human physiology (the gut microbiome, for example) as they are to effects in the environment and they merit a separate review.

Eligible exposure

RF EMF in the frequency range 100 kHz–300 GHz, either applied directly in experiments or from existing anthropogenic sources in the environment. We will exclude RF EMF at very high levels used to purposely heat different species such as for pest control or pre-treatment of seeds to improve germination. However, thresholds above which these thermal effects are apparent will be noted, for the purpose of gauging safety margins in existing exposure standards.

Eligible comparators

Sham exposure, no exposure beyond the background exposure level (which can be assumed to be negligibly low), or exposure at a lower level.

Eligible outcomes

All outcomes related to the studied population, including but not limited to biological/physiological endpoints, growth/development, behaviour and population abundance/decline.

Eligible types of study design

Experimental studies conducted in situ (by applying RF EMF in the natural environment) or ex situ in the laboratory and observational studies conducted in the natural environment (with existing anthropogenic RF EMF sources). Review articles will be excluded from the systematic map however they will be used as part of the supplementary search to identify potentially relevant research articles.

A list of articles excluded at the full text stage citing the reason for exclusion for each article will be provided as additional material in the final systematic map.

Study validity assessment

No formal validity/risk of bias assessment of included studies will be conducted. However, we will conduct a narrative assessment of important study design characteristics including exposure assessment, use of relevant control, appropriate statistical analyses and assessment of other exposures/factors related to the outcome in less controlled ex situ studies. The systematic map will provide a thorough description of study methods and characteristics and identify subtopics for further complete synthesis of results including a formal validity assessment in systematic reviews.

Data coding strategy

To ensure data is extracted in a consistent and repeatable manner, two reviewers will independently extract data from a random list of 10 included papers. The data extracted will be compared, and if any inconsistencies occur, the review team will add further specifications to the data categories. The data extracted from included studies will be recorded in an Excel spreadsheet. Extracted data will include but not be limited to:

- Bibliographic Information
- Publication type (journal article, book, thesis etc.)
- Type of study (experimental, observational, both)
- Setting (in situ, ex-situ, both)
- Study location (country)
- Taxonomic information (animal or plant, class, species)
- Sample size
- RF EMF exposure information (source, frequency, duration, intensity, specific absorption rate, modulation)
- Validity of exposure assessment
- Exposure above or below the human protection limit (ICNIRP guidelines general public limit for localised exposure)
- Outcome(s)
- Other covariates (for example different weather factors, light exposure and other anthropogenic radiation)
- Study limitations.

Where relevant data is missing, the review team will attempt to contact the authors with a request for data. The extracted data will be used to assess the range and extent of effects of anthropogenic RF-EMF on animals and plants in the environment.

Study mapping and presentation

The final systematic map will describe the review process and present evidence of categorised data from all included studies. A ROSES flow diagram illustrating the study eligibility process with the number of articles included in each stage will be presented [35]. A database of all the included and excluded articles will be published as additional material to the main manuscript. The database will include the meta-data of included articles, the rationale for each excluded article and the list of potentially relevant articles with full text not available. To ensure reusability and long-term preservation, the database will be made available on the ARPANSA website.

The systematic map will provide a narrative synthesis, supported by tables and figures, on the volume and

characteristics of the evidence base according to taxonomic groups, types of studies, exposure parameters and outcomes. A narrative assessment of the quality of evidence as well as the role of other environmental/anthropogenic factors will also be presented. Subtopics will be identified and the heterogeneity between study characteristics will be described within each subtopic.

The systematic map will identify possible knowledge gaps (unrepresented or underrepresented subtopics that warrant further primary research) and knowledge clusters (well-represented subtopics for full synthesis by a systematic review) by cross-tabulating key meta-data variables (e.g. taxonomic groups, exposure characteristics and outcomes) in heat maps, charts or other data visualization methods. Based on these results, recommendations will be made on priorities for future original research and further analyses/systematic reviews on the impacts of RF EMF on animals and plants in the environment.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13750-021-00252-w.

Additional file 1. Roses form.

Additional file 2. Boolean Search Strings.

Additional file 3. Comprehensiveness of the search test.

Authors' contributions

The initial review questions were developed by KK and AW. CBr and KK developed the search and data extraction strategies. KK and CBr wrote the manuscript protocol with contributions from AW, SL and CBh. All authors read and approved the final manuscript.

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Availability of data and materials

Data sharing is not applicable to this publication as no datasets were generated or analysed for the systematic map protocol.

Declarations

Ethics approval and consent to participate

No ethics approval and consent to participate was required.

Consent for publication

No consent for publication was required.

Competing interests

KK, CBr, CBh and SL as part of their employment at ARPANSA are involved in the provision of advice to the Australian Government, Australian States and Territories and the general public on the effects and risks of exposure to ionising and non-ionising radiation. KK and SL are also members of the main commission and scientific expert group, respectively, of the International Commission on Non-Ionizing Radiation Protection where they contribute in the development and dissemination of science-based advice on limiting exposure to non-ionizing radiation. KK, AW and CBr are members of systematic review teams into the WHO assessment of health effects of exposure to radiofrequency electromagnetic fields. No member of the mapping team will be involved in screening or extracting data from a study in which he or she is an author.

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