



Radiofrequency noise as an emerging ecological exposure: lessons from migratory bat navigation

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INTRODUCTION

Lindecke *et al.* provide a timely impetus for environmental exposure science^[1]. Their study reports that brief exposure to weak broadband radiofrequency (RF) fields disrupted the subsequent departure orientation of migratory soprano pipistrelle bats, while control bats oriented in the expected migratory direction. The finding matters because it concerns a sublethal behavioural endpoint, not mortality or overt physiological damage and because orientation is a process through which small disruptions could plausibly scale into ecological consequences if they occur in the wrong place, at the wrong time, or in sensitive species.

This Commentary uses the work of Lindecke *et al.* as a starting point rather than as an isolated case study^[1]. We ask whether anthropogenic RF noise should be considered not only through human-safety or technical-compliance frameworks, but also as a potential ecological exposure. Our argument is cautious: the study does not prove that RF noise is a widespread conservation threat, but it does reveal a gap in how environmental exposure assessment currently treats electromagnetic fields in landscapes used by wildlife.

BIOLOGICAL MEANING AND LIMITS OF THE FINDING

Orientation and navigation are central to bat ecology, yet remain among its major unresolved questions^[2]. Migratory bats rely on sensory systems beyond echolocation to achieve homing, long-distance movement and migration, including a magnetic compass calibrated against the sun's position at sunset^[3-5]. This compass is not fixed: migratory bats show heightened sensitivity to changes in magnetic inclination specifically during the compass-calibration period around sunset, when directional information for the night's flight is set^[5]. Earlier field and experimental studies also reported reduced bat activity near radar installations and during exposure to a portable radar source^[6,7]. Those studies examined GHz-range radar exposure and foraging activity rather than the broadband RF-noise effects on migratory orientation



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investigated by Lindecke *et al.*, but they are important antecedents to the present evidence base^[1].

Lindecke *et al.* add a striking behavioural result to this picture^[1]. Soprano pipistrelles (*Pipistrellus pygmaeus*) were exposed for approximately 30 min to weak broadband RF noise spanning approximately 0.01–300 MHz during sunset calibration, after sunset, or immediately before release. Exposed bats showed random departure orientation, whereas unexposed controls maintained seasonally appropriate headings; disorientation persisted for several hours after exposure ended, a carry-over effect extending well beyond the RF source itself. This is the first evidence that brief broadband RF noise can disrupt migratory orientation in a mammal, but it should not be interpreted as the first report of an RF-associated behavioural response in bats^[6,7]. The underlying sensory mechanism remains unresolved. RF disruption has often been discussed in relation to radical-pair magnetoreception, but the Lindecke *et al.* experiment does not establish that mechanism^[1], and recent work in pigeons supports an alternative, light-independent electromagnetic-induction pathway involving the vestibular system^[8]. Moreover, the exposure-system information available for the bat study does not provide every engineering and dosimetric parameter needed for independent reconstruction and full evaluation of ecological relevance.

The ecological significance follows from what migratory orientation serves: the exploitation of spatially and temporally variable resources under time pressure, informed by meteorological events^[9] and food availability^[10]. RF-radiofrequency electromagnetic field (EMF) exposure has been largely absent from syntheses of urbanisation and other global threats to bats, which emphasise habitat loss, fragmentation, artificial light, noise, climate change and disease^[11–13]; Lindecke *et al.* introduce RF noise as a further component of the sensory environment requiring investigation^[1]. The RF levels used were within the range reported for some anthropogenic environments and below the human-reference levels in ICNIRP guidelines^[1,14]. This comparison identifies a wildlife research question; it does not demonstrate that compliant RF sources cause serious environmental or human harm. Wireless technologies provide substantial societal benefits, and the term “RF-EMF exposure” is therefore used here instead of treating all anthropogenic electromagnetic fields as pollution. The experiments were conducted in a cue-deprived flight room, without celestial cues, landscape features or natural soundscapes; such cues may compensate for RF-induced disorientation under field conditions. Population-level consequences, generality beyond soprano pipistrelles and field-realistic dose-response relationships remain unestablished.

THE EXPOSURE ASSESSMENT GAP

The central exposure-assessment gap is not unique to bat navigation. Evidence exists across animals and plants, but remains taxonomically uneven, methodologically heterogeneous and rarely connected to field-realistic exposure assessment^[15]. Bat navigation is used here as a focused case through which to examine this broader problem. RF-EMFs are commonly discussed through telecommunications infrastructure, occupational exposure, consumer-device use, source regulation and human-health protection^[14,16]. These are necessary frameworks, but they do not fully describe the exposure environment through which non-human organisms move. For ecological interpretation, the relevant questions include where fields occur, which frequencies and modulations are present, how intensities vary through time and whether those patterns intersect with sensitive behaviours.

Environmental RF-EMF sources include radio and television broadcasting, mobile-communication base stations and handsets, Wi-Fi and other wireless networks, and civil, weather and military radar^[6,7,16]. Exposure may vary between urban and rural settings, near and far from fixed transmitters, around built infrastructure and transport corridors^[17], and across daily, seasonal and technological cycles, including step-changes from new network generations^[18]. A migrating bat is therefore not exposed to a single generic level, but to a changing mixture of signals and noise across frequencies, places and times.

Karipidis *et al.* illustrate this broader evidence gap directly: their systematic map of anthropogenic RF-EMF impacts on animals and plants finds that evidence remains sparse, unevenly distributed across taxa and rarely designed to test field-realistic exposure regimes^[15]. Previous perspectives have also raised concerns about wildlife orientation, radiotelemetry and possible effects on insects and other taxa^[19,20]. These publications motivate further work but do not establish a general causal effect across species or environments. Ecological exposure assessment adds further complications: mobile organisms, species-specific perception, behavioural endpoints, poorly characterised background fields and limited real-world monitoring. These limitations define the methodological challenge rather than a presumption of harm.

TOWARDS ECOLOGICAL RISK ASSESSMENT

A useful next step is to position RF noise within ecological risk assessment rather than only within anthropocentric protection models. Bréchnac^[21] argued that protection frameworks for physical stressors need to move beyond human-centred assumptions and consider ecological receptors and ecosystem-level processes. Similarly, Solomon and Sibley^[22] provide a broader ecological risk framing in which stressors are interpreted through exposure, effects, resilience, community responses and ecosystem function.

For RF-EMF, this means that evidence should be organised around exposure pathways, sensitive taxa, behavioural or physiological endpoints and the ecological contexts in which disruption would matter. The question is not whether every RF field is harmful, nor whether a single experiment can establish population-level risk. The question is whether monitoring and assessment systems can detect biologically meaningful exposure patterns. A biological counterpart should distinguish migratory from resident species, treat generalisation from soprano pipistrelles as untested, prioritise the compass-calibration window around sunset and consider other orientation cues that might counteract RF effects^[5]. Where new RF-emitting infrastructure could intersect with sensitive habitats or species, the mitigation hierarchy provides a proportionate framework: avoid exposure in sensitive locations where practicable, minimise unavoidable exposure through siting and technical design, monitor outcomes and apply restoration or offsetting only where residual effects are demonstrated^[16].

Future work should therefore connect field-realistic exposure measurement with biologically interpretable endpoints. Priorities include frequency-resolved monitoring, spatial exposure mapping across urban-rural gradients, temporal sampling during migration and coordinated studies at roosts, commuting routes, release sites and migration corridors. Bat-specific dosimetry is needed to relate external field measurements to absorbed dose across body size, posture, flight behaviour, frequency and modulation. Studies should also account for co-stressors such as artificial light, acoustic noise, habitat fragmentation, wind-energy infrastructure and climate-driven shifts in migration timing. Integrating bats and their insect prey within the same study designs would help test whether any RF-associated changes in insect abundance, diversity or behaviour could generate indirect, cascading effects on bat foraging and condition^[20].

Alongside these biological and ecological dimensions, RF-EMF exposure itself must be characterised in sufficient detail. Because studies use different frequencies, bandwidths, exposure durations, field strengths and modulation patterns^[15], assessment should report these parameters together with spatial uniformity, background fields, calibration, uncertainty and organism-specific dose, rather than relying only on total or averaged exposure.

CONCLUSIONS

The research by Lindecke *et al.* should be read neither as a final verdict on RF-EMF effects nor as an isolated observation in bat research^[1]. Together with earlier radar studies^[6,7], it opens a tractable question about how

frequency-specific, time-varying RF exposure may interact with wildlife behaviour. The broader evidence base spans multiple taxa^[15,19,20], while mechanisms, field-realistic dose-response relationships and population-level consequences remain uncertain. Progress requires transparent exposure reporting, species-specific dosimetry, ecologically realistic experiments and proportionate application of the mitigation hierarchy where sensitive receptors may be exposed.

DECLARATIONS

Authors' contributions

Jointly drafted the Introduction, the section “Towards Ecological Risk Assessment”, and the Conclusion: Margaritis, E.; Zamora-Gutierrez, V.

Drafted “The Exposure Assessment Gap”: Margaritis, E.

Drafted the “Biological Meaning and Limits of the Finding” and contributed to the biological interpretation within “Towards Ecological Risk Assessment”: Zamora-Gutierrez, V.

Both authors reviewed and edited the manuscript and approved the final version.

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Ethical approval and consent to participate

Not applicable.

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