Proceedings of the MASTS Cross-Sectoral Working Group on the Impact of Electromagnetic Fields (EMFs) on Marine Ecosystems

A Cross-Sector Framework for Understanding and Managing the Cumulative Effects of Anthropogenic EMFs in the Marine Environment

MARINE ALLIANCE FOR SCIENCE AND TECHNOLOGY FOR SCOTLAND

Abstract

Rapid expansion of offshore renewable energy infrastructure has led to a concomitant increase in anthropogenic electromagnetic fields (EMFs) in marine environments. Although many marine taxa detect and respond to natural geomagnetic and electric cues, the ecological significance of exposure to anthropogenic EMFs remains poorly resolved. A multi-sector Working Group convened by the Marine Alliance for Science and Technology for Scotland (MASTS) identified critical knowledge gaps, barriers to data access, and opportunities for coordinated scientific and governance action. This paper synthesises those discussions and outlines a proposed framework for evidence generation, monitoring, and regulatory reform to support responsible offshore energy development.

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1. Introduction

The transition to net-zero energy systems has accelerated the deployment of offshore renewable energy, particularly offshore wind installations in UK and Scottish waters. These developments require extensive subsea networks of export cables, inter-array cabling, interconnectors such as EGL2, transformers, and offshore substations, all of which generate EMFs of anthropogenic origin.

Marine organisms - including elasmobranchs, eels, salmonids, crustaceans and marine mammals - have evolved diverse electro- and magnetosensory mechanisms and use natural EMF cues for navigation, foraging, orientation, and communication. The introduction of novel EMF sources therefore raises questions about potential interference with biological processes, both at individual and population scales.

Despite significant technological readiness to potentially measure, model, and monitor EMFs, the Working Group identified that limited access to operational data, an absence of agreed standards and a lack of coordinated governance, constrain the development of robust ecological assessments. This Proceedings paper articulates the current state of knowledge, key uncertainties, and recommended pathways for coordinated, scientifically grounded action.

2. Current Understanding

2.1 Biological Sensitivity and Detection Capabilities

A wide range of taxa demonstrate sensitivity to natural EMFs, with species exhibiting electroreception, magnetoreception, or both. Animals, such as lobsters and crabs, sharks, rays, eels, salmon, dolphins, whales and sea turtles, can discriminate changes in EMF intensity and rely on cues in contexts such as navigation, communication, prey detection, or mating behaviour.

Anthropogenic EMFs arise principally from:

- Alternating and direct current export cables
- Inter-array and interconnector cabling within turbine arrays and between arrays and landfall.
- Offshore substations and transformers
- Dynamic cables associated with floating wind infrastructure

The resultant EMF signatures vary according to cable geometry, burial depth, sediment characteristics, electrical load, operational status, seabed dynamics, and broader environmental conditions.

Empirical studies demonstrate that anthropogenic EMFs are detectable by marine species and can induce changes in swimming behaviour, orientation, physiological responses, or activity levels. The ecological meaning of these responses—whether they represent attraction, avoidance, alteration of movement pathways, or negligible effects—remains uncertain and species dependent.

2.2 Technological Capabilities and Data Limitations

Although diverse sensors (including magnetometers, fibre-optic systems, AUV-mounted instruments, and low-cost EMF loggers) are available, deployment remains fragmented. Existing operational datasets—such as electrical load profiles, cable temperature, geotechnical conditions, burial variability, and inspection records—are rarely accessible to researchers due to the citing of commercial sensitivities, the difficulty of achieving agreement between partners of individual wind farms, and lack of mandated sharing mechanisms.

Consequently:

- Empirical evidence is sparse and often short-term
- Modelling relies on unverified assumptions or incomplete environmental inputs
- There is limited ground-truthing of predicted EMF fields
- Exposure scenarios in the literature frequently fail to represent realistic operational conditions

3. Key Knowledge Gaps

3.1 Biological and Ecological Thresholds

Uncertainty persists regarding:

- Species- and life stage–specific sensitivity levels
- Mechanistic understanding of electro- and magnetosensory systems
- Realistic exposure scenarios accounting for behavioural versus physiological endpoints of significance
- Cumulative impacts across arrays, regions and multiple project lifecycles, and effects on commercially important and OSPAR or PMF (Priority Marine Features) species
- Population- and ecosystem-level consequences, particularly in terms of migration, connectivity, reproduction or survival

Crucially, the absence of evidence for population impacts does not constitute evidence of their absence; instead, it reflects limited long-term datasets, restricted replication, and a lack of integration across ecological scales.

3.2 Environmental and Geotechnical Context

Exposure and ecological relevance vary with a range of interacting environmental and engineering factors:

- Species encounter rates in relation to frequency, and life stage
- Sediment type, mobility and habitat change
- Burial depth, scour processes and the presence of exclusion zones

- Seabed morphology, hydrodynamics and temperature shifts
- Climate pressures and other stressors
- Multi-cable corridors and spatial clustering of infrastructure
- Dynamic behaviour of free-spanning sections of cable, particularly in floating wind systems

New engineering configurations may introduce EMF signatures not yet characterised in the literature.

4. Cross-Sector Barriers

4.1 Data Access, Standardisation, and Governance

The Working Group identified restricted access to operational data as the most significant barrier to progress. This includes access to data on cable load and temperature, EMF emission profiles from manufacturers, geotechnical conditions and burial depth variability, inspection data from ROV surveys and time-series data held by grid operators. Corporate restrictions through NDAs (Non-Disclosure Agreements) and commercial concerns over IP protection and liability, often prevent researchers, regulators, and other developers from accessing relevant datasets. This leads to over-reliance on modelled estimates, limitations in the validation of EMF models and insufficient development of cumulative impact assessments.

Additionally, monitoring approaches differ markedly across projects, and no UK-wide standard exists for EMF measurement, reporting, or baseline data definition. Without such baselines, it is extremely difficult to determine where sensitive habitats or species overlap with cables, how EMF exposure varies, and whether EMF-related changes are occurring. This prevents comparability across sites, cumulative assessments at regional scale, transferability of results and consistent regulatory review.

Consequences of a lack of standardisation and governance can also be seen in the inconsistency of Environmental Impact Assessments (EIAs). The current EIA system was considered insufficiently equipped to address EMFs, due to inconsistent or insufficient expertise, outdated or narrow literature use, limited requirements for monitoring, and inadequate treatment of cumulative or population-level effects. The Working Group agreed that EIAs must shift from a species-by-species approach to a population-level and ecosystem-level approach that reflects the scale of modern offshore wind development.

4.2 Misalignment of Development and Scientific Timescales

Offshore wind development progresses more rapidly than ecological research and regulatory adaption. Without strategic coordination, existing knowledge gaps are at risk of persisting across multiple development cycles.

5. Engineering, Monitoring, and Modelling Considerations

5.1 Free-Spanning and Geotechnical Uncertainty

Cable sections lifted above the seabed (free spans) alter EMF exposure fields and may persist or evolve over time. Understanding free-spanning requires better sediment mobility data, detailed bathymetry and predictive models integrating geological and engineering variables.

5.2 Real-Time Monitoring Potential

Operational systems already generate substantial real-time data (e.g., cable load and temperature, vessel proximity data and maintenance logs). Integrating EMF sensors into existing AUV/ROV surveys, fishing gear, or tagged wildlife platforms offers cost-effective pathways for long-term monitoring.

5.3 Modelling Constraints

Modelling efforts are hampered by:

- Lack of validated empirical data
- Incomplete representation of complex multi-cable configurations
- Insufficient biological data to parameterise exposure–response relationships

Field-based datasets are required to transform models into reliable decision-support tools.

6. Framework for Coordinated Action

6.1 Establishment of an EMF Coordination & Governance Body

The Working Group recommends the creation of a regional or national EMF coordination body (potentially hosted by MASTS) with representation from regulators, industry, developers, manufacturers, researchers, and fisheries stakeholders. Its functions would include:

- Setting technical and ecological monitoring standards
- Mandating EMF data sharing and managing a central repository of EMF-relevant data, with appropriate protection for commercial sensitivity. An EMF repository could include cable specifications and operational data, geotechnical and habitat layers, EMF sensor data, EIA baselines and long-term ecological studies.
- Facilitating cross-border dataset integration and monitoring
- Engaging manufacturers and system operators
- Aligning UK approaches with OSPAR and other international frameworks
- A reform of the EIA process

Recognising EMFs as a regulated environmental stressor—analogous to underwater noise—would enable the development of defined thresholds, mandatory monitoring requirements, and transparent mitigation expectations.

6.2 Standardised Data Collection and Reporting

A UK- or North Sea–wide standard should define:

- Species sensitivity testing
- Sensor types and calibration procedures
- Spatial and temporal sampling resolutions
- Metadata and reporting requirements
- Minimum monitoring durations
- Approaches for validating ecological models
- Prioritisation of foundational research and development of realistic exposure designs. Shift from short-term lab studies towards integrated lab–mesocosm–field frameworks. Improved communication of results to include clear, policy-ready messages.

Industry is encouraged to share operational data proactively, co-develop EMF testbeds, and participate in joint funding schemes to minimise duplication and ensure consistency.

By addressing insurers' data needs uncertainty about EMF impacts could be reduced, which would benefit operational insurance and long-term risk management.

6.3 EMF Testbeds and Integrating into Routine Operations

A controlled "natural laboratory", including infrastructure relevant to floating and fixed-bottom wind, would support:

- Species response experiments
- Model validation
- Methodological training
- Manufacturer and consultancy engagement

Routine integration of EMF sensors into operational inspections and fisheries activity would generate long-term datasets at minimal incremental cost. EMF consideration should be required at all stages of consenting. Baseline data collection must begin pre-construction, monitoring must continue through operation and decommissioning, and data must be transferable if project ownership changes.

6.4 Mixed and Adaptive Funding Models

Given the shared benefits of uncertainty reduction, long-term funding should draw upon government, developers, insurers, and licensing contributions. A centralised monitoring fund could support independent science, ensure dataset continuity, and reduce duplication across individual projects.

7. Conclusions

The expansion of offshore renewable energy necessitates a parallel expansion of scientific understanding and governance surrounding anthropogenic EMFs. The technology to study EMFs is mature; the principal constraints are coordination, access to operational data, standardisation, and political will.

The Working Group identifies five overarching priorities:

1. Align incentives for industry, regulators, insurers, and researchers around uncertainty reduction and risk management.
2. Mandate EMF data sharing and monitoring across project lifecycles.
3. Establish shared test sites and monitoring infrastructures to accelerate method development.
4. Invest in coordinated, long-term scientific research that integrates laboratory, mesocosm, and field approaches.
5. Reform regulatory processes to support population-level and ecosystem-level assessments.

Implementing these recommendations would position Scotland and the UK as leaders in responsible offshore renewable development. It would balance climate commitments with marine biodiversity protection and scientific rigour, whilst also feeding useful knowledge and understanding into the engineering design and operational processes.

Appendix A

A1. Purpose and Background

MASTS, the Marine Alliance for Science and Technology for Scotland, is a consortium of 18 organisations engaged in marine science and promoting dialogue, co-ordination and collaboration between sectors to support the vision of clean, healthy and safe marine and coastal environments. (Contact: masts@st-andrews.ac.uk)

In November 2025 a MASTS Working Group convened representatives from research, industry and government at the National Robotarium, Scotland, for a Scoping Meeting to discuss sectoral perspectives on the impact of EMFs on marine ecosystems and to identify shared priorities for evidence generation, monitoring, and policy development.

The outputs from these discussions formed the basis for this document with the goal of providing key stakeholders with recommendations towards improved marine stewardship and collaborative innovation.

A2. Meeting Attendees

The following individuals and organisations attended the MASTS Scoping Meeting at the National Robotarium in November 2025:

- Communities Inshore Fisheries Association (CIFA) - Andrew Whiston
- Copenhagen Offshore Partners - Fraser Malcolm
- Edinburgh Napier University - Matthew Wale
- EvolvEnergies - Conor Wells
- Fugro - Andy Matkin
- Heriot-Watt University - Iain Shirlaw and Alastair Lyndon
- NatureScot - Kirstie Dearing
- MASTS – Mark James
- Queen’s University Belfast - Patrick Collins
- Scottish Government - Zoe Hutchison and Kirsty Wright
- St Abbs Marine Station - Kevin Scott and Petra Harsanyi
- TechnipFMC - Alan Dobson
- The D’Arcy Thompson Simulator Centre - Moya Crawford and Charlie Bavington
- University of Edinburgh - Brian Sellar
- Xodus Group - Jack Poleykett

MASTS EMF Scoping Meeting, Nov 2025, National Robotarium, Scotland

A3. Wider Stakeholder Group

The following organisations were consulted on the Working Group's purpose and will remain updated as its work progresses:

- 50Hertz
- Blue Float Energy
- bp UK
- Buchan Offshore Wind
- Crown Estate Scotland
- EDF/NNG
- Europacable
- European Marine Energy Centre (EMEC)
- Energie Baden-Württemberg AG (EnBW)
- Falck Renewables/Renantis
- Flotation Energy
- Fred. Olsen Renewables
- Inch Cape Offshore Limited
- Opergy
- ORE Catapult
- Orsted
- Red Rock
- Renewables Grid Initiative
- Runde Environmental Centre and NIVA
- Scotia Supply Co Ltd
- ScotMER
- Scottish Fishermen's Federation (SFF)
- Scottish Power
- Scottish Environment Protection Agency (SEPA)
- Shell SPR
- Siemens
- SSE Renewables
- SOWEC
- Sumitomo Electric Industries
- Thistle Wind Partners (TWP)

A4. Meeting Agenda

Please see below the full meeting agenda as circulated prior to the meeting:

A. Welcome & Opening Remarks | Speakers: Iain Shirlaw (Heriot-Watt University) & Stewart Miller (The National Robotarium)
B. Keynote Presentation "Bridging the gaps between EMF science, industry practice, and decision-making" | Speaker: Jack Poleykett (Xodus Group)
C. Sectoral perspectives on challenges and knowledge gaps
    a. "The ELASMO Project: Establishing the ElectroSensory Ecology Laboratory at Queen's University Belfast" | Speaker: Patrick Collins (Queen's University Belfast)
    b. "From the Lab to the Sea: Understanding and Overcoming the Challenges of EMF Research" | Speaker: Kevin Scott (St Abbs Marine Station)
    c. "Signals in the Sea: Inshore Fishers' Perspective on EMFs and Cumulative Impacts" | Speaker: Andrew Whiston (CIFA/Communities Inshore Fisheries Association)
    d. Industry perspectives | Speaker: Alan Dobson (TechnipFMC)
    e. Government perspectives | Speaker: Zoë L Hutchison (Offshore Wind Directorate, Scottish Government)
D. Open Discussion Round
E. Breakout Sessions A&B: Identifying Knowledge Gaps, Research Needs & Funding Areas
F. Report-Out & Plenary Discussion
G. Next Steps
