Assessing the potential for offshore infrastructure as platforms for environmental monitoring

First published September 2022

Natural England Commissioned Report NECR446

www.gov.uk/natural-england

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Project details

This report should be cited as:

Offshore Renewable Energy Catapult. 2022. *Assessing the potential for offshore infrastructure as platforms for environmental monitoring*. NECR446. Natural England.

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Further information

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Executive summary

With the rapid growth of the UK's offshore wind industry, there are thousands of offshore assets that could potentially provide valuable locations and opportunities for environmental data collection. As such, there is an opportunity to develop a process for both retrofitting environmental monitoring devices onto existing assets, and to include sensor provision as part of the manufacturing process and installation of new offshore wind infrastructure. With improved continuous monitoring of the offshore environment, a more detailed picture of the impacts of anthropogenic on the local and macro marine environment can be created

This project was therefore established to investigate the feasibility of using offshore assets for hosting environmental monitoring sensors. The first phase of the project delivered a technical review of the available technologies that exist in the market currently, and the second phase facilitated a technical engagement process with offshore wind farm developers and environmental sensor manufacturers to determine the technical, practical and logistical considerations of retrofitting and integrating sensors into turbine designs, as well as the potential challenges.

It was found that there are opportunities for using existing and future offshore infrastructure to support wider offshore environmental monitoring, particularly in respect of ornithology, bats, marine mammals, and fish. In many cases further work would be required to address existing practical challenges and uncertainties, therefore collaboration between regulators, key environmental stakeholders, wind farm developers, and sensor manufacturers will be key to addressing these challenges going forward.

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Nomenclature

AC	Alternating Current
CDOM	Coloured Dissolved Organic Matter
CPR	Continuous Plankton Recorder
CPU	Central Processing Unit
DAQ	Data Acquisition
eDNA	Environmental DNA
EIA	Environmental Impact Assessment
EMF	Electromagnetic Field
EPS	European Protected Species
GES	Good Environmental Status
GLS	Global Location Sensor
GPS	Global Positioning System
GWO	Global Wind Organisation
MPCP	Marine Pollution Contingency Plan
MRI	Magnetic Resonance Imaging
O&M	Operation and Maintenance
OEMP	Offshore Environmental Management Plan
OEMs	Original Equipment Manufacturers
ORJIP	Offshore Renewables Joint Industry Programme

PCR	Polymerase Chain Reaction
PTT	Platform Transmitter Terminal
ROV	Remotely Operated Underwater Vehicle
SAC	Special Areas of Conservation
SCADA	Supervisory Control and Data Acquisition
SONAR	Sound Navigation and Ranging
USVs	Unmanned Surface Vehicles
VDSL	Very High Speed Digital Subscriber Line
WeBs	Wetland Bird Survey

Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

1 Introduction

Natural England have identified that with the rapid growth of the UK's offshore wind industry, there are thousands of offshore assets that could potentially provide valuable locations and opportunities for environmental data collection. As the industry aims to deliver up to 50GW of capacity by 2030 (UK Government, 2022), there is an opportunity to develop a process for both retrofitting environmental monitoring devices onto existing assets, and to include sensor provision as part of the manufacturing process and installation of new offshore wind turbines and substation infrastructure. With improved continuous monitoring of the offshore environment – subsea, the splash zone and the atmospheric zone – a more detailed picture of the impacts of anthropogenic on the local and macro marine environment can be created. Additionally, there is an opportunity to utilise existing oil and gas infrastructure in the North Sea.

This project was therefore established to investigate the feasibility of using offshore assets for hosting environmental monitoring sensors. The first phase of the project delivered a technical review of the available technologies that exist in the market currently. This technology review assessed the parameters and environmental characteristics that relevant technologies can monitor, as well as the scope of their applications and the benefits and drawbacks of each.

The second phase of the project involved stakeholder engagement through questionnaires and interviews with offshore wind farm developers and environmental sensor manufacturers in order to gauge the technical, practical and logistical considerations of retrofitting and integrating sensors into turbine design, as well as potential challenges, including the behaviour, design, and operation of embedded or retrofitted sensors.

This report, being the main deliverable of the project, summarises the findings of this technology review and stakeholder engagement process, and outlines findings and recommendations relating to the potential installation of environmental monitoring sensors on offshore infrastructure.

1.1 ORE Catapult/ ODSL

ORE Catapult is the UK's flagship technology innovation and research centre for offshore wind, wave and tidal energy. ORE Catapult is playing a leading role in the delivery of the offshore wind sector deal (partnership between UK Government and offshore wind industry), including the Offshore Wind Growth Partnership, focused on enhancing the competitiveness of UK supply chain companies for supplying into the domestic and export markets. ORE Catapult has also developed and maintains technology roadmaps in order to co-ordinate R&D funding and activity across agreed industry priorities. This provides ORE Catapult with a unique broad and objective perspective on the UK and global offshore wind industry.

The work proposed herein was performed and managed by ODSL, a wholly owned subsidiary of Offshore Renewable Energy Catapult. ODSL undertakes commercial activity on behalf of Offshore Renewable Energy Catapult through a management agreement governing the trading between the two companies. This ensures that work by ODSL is undertaken on an open, fair and commercial basis that reflects the arm's length nature of the business relationship. All agreements for Services and confidentiality are applicable to both Offshore Renewable Energy Catapult and ODSL.

2 Technology review

The technology review is structured around the following key themes of environmental interest that were identified at the outset of the project through discussion between ORE Catapult and Natural England:

- Electromagnetic Fields
- Ornithology and bats
- Water Quality (including algae, plankton, and trace metals)
- Study of fish
- Marine Mammals
- Seabed

In relation to each theme, this technology review identifies the relevant sensor types that are currently available, their operating principles, as well as an initial discussion on their potential suitability for installation on offshore infrastructure. These preliminary findings have been used to guide the second phase of the project, which delivered the stakeholder engagement.

2.2 Electromagnetic fields

2.2.1 Available sensors

When performing sub sea surface electromagnetic field (EMF) surveys, it is necessary to use different sensing mechanisms in order to measure the two distinct EMF components: electric and magnetic.

Electric field sensors utilise pairs of electrical conductors, or electrodes. These are typically offered as commercial solutions, however, given the relative simplicity of the arrangement, custom arrangements are also sometimes used.

Magnetic fields are measured using magnetometers, which is a collective term for devices that can detect the strength and/or direction of magnetic fields. Historically, the orientation of the Earth's naturally occurring magnetic field (the geomagnetic field) was observed using simple compasses, which utilise a magnetised needle that pivots in response to the magnetic field direction. Modern subsea surveys however use more advanced solutions to take both vector and scalar field measurements. A common approach involves the use of fluxgate magnetometers, which provide vector field measurements (both strength and direction). However other commercial solutions make use of Overhauser effect magnetometers and caesium vapour magnetometers, which both provide scalar field measurements (strength only).

2.2.2 Operating principles

Electric field sensors

Electric field measurements are made using pairs of electrodes, the ends of which are separated by a fixed distance and submerged in the water. In a typical configuration, the electrodes are connected via an electrical circuit containing a voltmeter. When the electrodes are subjected to an electric field, a potential difference, or voltage, is generated within the circuit, which is measured by the voltmeter. The voltmeter signal is then amplified and processed by an analogue-to-digital converter so that the data can be recorded. In order to take full, three-dimensional electrical field measurements, three pairs of electrodes are arranged in a triaxial configuration.

Magnetic field sensors

The operating principal behind magnetometers varies according to the sensor type. In the case of fluxgate magnetometers, a small metal core of high magnetic permeability is wrapped with two coils of wire: a driving coil and a sensing coil. An alternating current (AC) is passed through the driving coil, causing a continuously reversing magnetic field to be generated around the metal core. A corresponding AC current is naturally generated within the sensing coil in response to the alternating magnetic field, and the AC current within the sensing coil is measured. In the absence of an external magnetic field, the input and output currents should match. However, when an external magnetic field is present, the magnetic saturation of the metal core is determined by both the current in the driving coil as well as the external magnetic field. As a result, the AC current in the sensing coil slips out of alignment with that of the driving coil, and the strength of the external field can be calculated based on the difference between the two signals. Three-dimensional vector magnetic field measurements can be obtained by using three metal cores (each with their own driving and sensing coils), arranged in a triaxial configuration.

Alternative approaches to measuring magnetic fields include the use of Overhauser effect magnetometers and caesium vapour magnetometers. Overhauser effect magnetometers utilise nuclear magnetic resonance – the same phenomenon that is used in magnetic resonance imaging (MRI) scanners in the medical industry – by detecting the spin polarisation of electrons or nuclei (typically hydrogen) resulting from the application of an external magnetic field. Caesium vapour magnetometers on the other hand utilise a laser to excite the electrons of caesium atoms to higher energy levels, while a photon detector measures the resulting change in quantum state. The application of an external magnetic field disrupts this effect, and the magnitude of the magnetic field can be inferred from the output of the photon detector. Unlike fluxgate magnetometers, which provide vector measurements, both Overhauser effect magnetometers and caesium vapour magnetometers provide scalar magnetic field measurements.

Existing commercial marine magnetometers supply tow cables, of length specified by the client, with appropriate terminations for connection of on-board cables and instruments. Many marine magnetometers are designed to be towed behind marine vessels to mitigate against potential interference with the recorded data. A SeaSPY system only requires 1W standby or 3W maximum, and can run from a 12V or 24V vehicle battery (Oceanscan Limited, 2022). Alternatively, EMF sensors can be powered by standard power lines, depending on the instrumentation selection. The tow cable can also be equipped for two-way communication using RS-232 serial data format or communication transmitted via a host Central Processing Unit (CPU). To record the data, appropriate software will be required on the logging computer. Some software packages/logging programmes may require Global Positioning System (GPS) to be enabled for data recording.

2.3 Ornithology and bats

2.3.1 Available sensors

There are several devices which can be used to monitor birds and bats in the offshore environment; they typically differ in their approach to tracking and data retrieval. Traditionally, bird tracking involves capturing a bird and attaching an external device such as GPS, Platform Transmitter Terminal (PTT), or Global Location Sensor (GLS) tag to it. The bird is then released and its movement is tracked via satellite positioning. GPS, GLS and PTT tags are suitable when target species are guaranteed to be in range of a receiving satellite, or the re-capture of the target is possible.

While existing offshore assets are unlikely to support the satellite-based GPS, GLS and PTT tracking methods, there may be opportunities to support alternative tagging approaches. For example, Motus Telemetry represents an international collaborative network that uses automated radio telemetry. This network relies on the use of radio transmitters (tags) which transmit radio waves detected by receiver stations deployed across the globe, and the information is subsequently uploaded to a central database. Fixing telemetry receiving stations on to offshore wind infrastructure could therefore facilitate the monitoring of birds and bats by supporting the collection of information from such radio transmitter tags.

Additionally, radar can also be used to detect the movement of birds and bats without needing to interfere with target species. Radar systems are a proven bird and bat monitoring system employed on offshore wind assets for hazard assessment, planning and strategic management purposes. Studies have been conducted which used a combination of cameras, rangefinders, and radar to identify and track birds and bats around turbines, (Skov, et al., 2018).

2.3.2 Operating principles

A GLS consists of a battery, light sensor, clock, and a memory chip. The light sensor records light levels periodically. The light level is plotted against time to infer the day-night cycle and thus the location of the bird. Solar midday varies by 1 hour per 15 degrees in longitude. This method of position tracking is accurate up to 150km as data can be easily obscured by clouds, plants or even feathers.

PTT trackers work with a system of satellites known as Argos, which is dedicated to environmental studies. The device sends a high frequency signal which is picked up by an overhead satellite. As the satellite passes over the signal the satellite witnesses a frequency shift in the signal, known as the Doppler effect. The position of the bird can be calculated with an accuracy up to 600m relative to the position of the satellite.

GPS is an established satellite positioning system. A GPS device's signal is detected by multiple satellites and the device's position is triangulated, typically with a high degree of accuracy (e.g. up to 75m). GPS and PTT systems have the advantage over GLS as data can be recorded and stored actively, not requiring the recapture of the bird, however, GLS devices can be mounted on smaller species due to their lighter weight. (Atkinson, Bird Tracking - A Masterclass, n.d.)

Motus Telemetry operates along similar principles to traditional radio telemetry; the system comprises three devices: a transmitter, antenna and receiver. The tag transmits information through radio waves, and each tag has a unique code for easier identification of individual targets. The Motus Telemetry network supports two main types of tags that transmit radio frequencies at 167 MHz and 434 MHz.

Radar monitoring operates on the echo principle, whereby short bursts of electromagnetic energy are transmitted and fragments of energy are reflected back to the antenna. The returned energy (the "echo") can be used to determine the direction and distance of the target species in relation to the antenna.

2.4 Water quality

2.4.1 Available sensors

Water quality can be defined as "the suitability of the water to sustain various uses or processes" (Meybeck, Kuusisto, A.Makela, & Malkki, 1996). In respect of the scope of this project, water quality considerations have focussed on measurements that are indicative of healthy marine life. Water quality sensors can encompass a range of parameters, including pH, turbidity, suspended solids etc. For the purpose of this report, fluorometers and spectrometers were investigated in respect of water quality monitoring due to their accuracy and reliability. Measurements of nutrients dissolved in the water, algae and plankton, and trace metals should be taken in order to build a comprehensive analysis of water quality. There are a number of 'off the shelf' solutions that have varying degrees of suitability for these applications.

Monitoring of plankton is also necessary to indicate the effects of climate change and pollution on marine environments. Continuous plankton recorders (CPR) can be used for this purpose. A CPR is a plankton sampling device that is typically towed from shipping vessels; water is filtered through the instrument, whilst plankton is retained by a silk filter (Marine National Facility, 2022) . Post-deployment plankton samples are taken for lab analysis and species type, abundance and distribution are used to indicate marine health.

2.4.2 Operating principles

Nitrate and Phosphate, two key chemicals in algae growth, can be measured using ultraviolet spectrometry. Spectrometry is the measurement of electromagnetic radiation absorbed or emitted from particles when exposed to an incident waveform. In this case, ultraviolet light passed through a sample fluid causes free electrons to change energy level, which correlates directly to a change in the observed spectra. Since every particle has unique spectral characteristics, the changes in the spectra can be used to identify the concentration of specific particles within the sampled material. (Gong, 2010)

Fluorometers are a specific kind of spectrometer that is used for the detection of fluorescent matter in the visible spectrum. Fluorescent matter can include, chlorophyll, blue-green algae (phycocyanin and phycoerythrin), and coloured dissolved organic matter (CDOM). The sampled material is excited by incident visible light which causes the material to emit fluorescent light. As with traditional spectrometry, analysing the emitted light then allows the sensor to measure a specific particle. (University of York, Dept. of Biology, n.d.)

Power requirements for Spectrometry sensors range from 8-15V, which is typically sourced via on-deck power sources. Devices are equipped for two-way communication via RS-232 connections, or data stored internally for retrieval post-deployment. Depending on product selection, the fluorometer may contain submersible internal batteries for longer-term deployments. Alternatively, the instrument requires external supply of at least 8-30V for operation.

2.5 Fish

2.5.1 Available sensors

Ichthyology, the study of fish, can be undertaken using a number of commercially available sensors. Submersible cameras, multibeam echosounders, acoustic receivers, and tags have all been used in academic studies to monitor fish populations. Therefore, to gain an understanding of the marine ecosystem around offshore infrastructure, multiple sensor technologies may be employed.

Submersible cameras have been widely used to date on both fish and the seafloor, however, they are generally restricted to shallow, clear waters. Some studies have explored the use of baited remote underwater stations to monitor elasmobranchs (Espinoza, 2020). Multibeam echosounders are able to provide highly accurate digital bathymetric models from which species distributions can be derived.

Echosounders are also capable of capturing data on fish, known as ‘Fish Finders’ which operate under a wider echo beam (Bathylogger, 2018). Acoustic receivers and tags are used to locate and identify fish in the surrounding areas passively, proving data on species population size and distribution (Lecours, et al., 2021).

Additionally, migratory fish can be monitored by using electronic tags for mapping or tagging fish which are released into the environment and then recaptured. These tags can either be affixed externally to fish or implanted. Data collected during deployment can be archived within the tag and retrieved post-deployment, or information can be transmitted via satellite in real-time. Acoustic telemetry has also been utilised as a method for fish monitoring, whereby receivers are deployed to detect and record information transmitted from compatible fish tags.

Tags are battery operated, depending on product selection, with typical power requirements ranging from 3-5V. Depending on the device, batteries can support an operational life typically ranging from 30 days up to 12 months.

Multibeam echosounders typically require a power supply in the range 19-74V, which can be supplied externally via the vessel or platform that the sensor is deployed from. Data transfer can be achieved via an ethernet link or VDSL (very high speed digital subscriber line). Depending on sensor selection, equipment hardware can support feedback rates of 30 frames per second. Higher refreshment rates of images creates smoother footage for end-user, and the sensor will usually detect which mode is appropriate to use based on vehicle speed etc (Tritech, 2022).

Environmental DNA (eDNA) presents an innovative method for monitoring fish species. To date, the technologies that support this type of monitoring have been relatively limited, and most commonly rely on manual techniques to extract cellular fish materials. However, recent studies have investigated an alternative to manual filtration by submerging membranes in the water column in order to collect eDNA samples. One study found that passive eDNA collection is a promising method for fish identification, and that the use of charged nylon membranes may be more effective than non-charged cellulose ester membranes (Goldberg, et al., 2019). The use of phylum Porifera has also been explored as a method for eDNA extraction, whereby the sponges were able to able to retrieve distinguishable samples of eDNA fragments (Mariani, Baillie, Colosimo, & Riesgo, 2019) . Both studies indicate that the use of innovative eDNA extraction techniques indicate could offer an important shift from active to passive monitoring. Due to the minimal human intervention relative to manual sampling, this approach could therefore be better suited to remote deployment on offshore infrastructure. It is likely that further research and development is required though before remotely eDNA monitoring becomes a commercially available solution.

2.5.2 Operating principles

Submersible cameras use optical lenses to capture visible light converting it to a digital image or video. They are therefore restricted to use in areas with sufficient lighting and water clarity. Submersibles can use either fixed or rotatable lenses, and the latter can be remotely operated to build a 360° view of the environment. Video and imagery can be used to identify fish abundance, either in real-time, or periodically with the use of image recognition technology (Marini S. , et al., 2018). A recent study investigated the effects of light intensity, turbidity, biofouling, and dense fish assemblages on an underwater camera for automated fish identification and fish abundance by capturing images every 30 minutes across a two year period (Marini S. , et al., 2018). The study identified constraints that limit recognition efficiency, such as biofouling, but it recommended that these technologies have potential in underwater research applications.

Cameras can be handheld and operated by divers, or (more commonly) mounted to Remotely Operated Underwater Vehicles (ROV), and have a typical power supply of 9-30V, which is supplied by on-deck sources. Cameras can be configured for remote control using RS232 & RS485 connections.

Echosounders are a type of sonar (sound navigation and ranging) device which are traditionally used to measure water depth (before any offshore infrastructure can be placed, surveys of the marine environment must be completed, often including the use of echosounders). During these surveys, an echosounder onboard a survey vessel sends a pulse of sound into the water via an underwater transducer or hydrophone. The echosounder's receiver measures the time of a pulse reflected by the seafloor to build an image of the bathymetry. Whilst the sea depth and seafloor condition can indicate the possible types of species in an area, it cannot indicate population size. However, multibeam echosounders or 'Fish Finders' use a much 'wider' echo beam that allows fish and other animals to be more clearly defined. The wider beam is achieved by using multiple beams in all directions instead of a single beam facing the seafloor, thus, allowing for greater data collection on schools of fish (Britannica, 2013).

Acoustic receivers and tags work on a similar principle to echosounders. Tags, which are orally implanted or attached externally to the fish, have a transducer that sends a signal similar to that of an echosounder. Multiple receivers/hydrophones placed around a site at fixed positions are used to triangulate the location, direction, and depth of a fish carrying a tag. Fish have been tagged and tracked in this manner over a large area, up to 10km between receivers, and this is dependent on the species range (Marine Conservation Society, 2022).

An additional possibility for acoustic receivers is to monitor the unique, naturally occurring low-frequency noise produced by many fish species. Acoustic receivers were used to study a healthy reef in South Sulawesi, Indonesia as part of The MARS Assisted Reef Restoration System (MARS, limited, 2022). Recordings from the healthy reef were compared to receivers deployed in degrading reef sites, with greater diversity observed in the healthier sites. This study highlighted that monitoring of underwater noise provides additional valuable data on the health of marine environments.

The combination of skin cells, faeces, saliva, and decomposing animal matter are the subject of eDNA analysis, as they all contain at least partially degraded DNA information which can be analysed by researchers. Samples of water (soil and seabed are also acceptable mediums) are collected and DNA is extracted using specialised equipment. A Polymerase Chain Reaction (PCR) is used to amplify the target DNA chain (using a primer that causes a DNA chain to repeat itself). The sample is then purified and a second PCR takes place in preparation for the DNA sequencing process. Once the sampled eDNA has been sequenced, identification of species is possible. DNA sequencing is highly accurate and is considered to be a crucial tool in the future of marine life analysis. However, one disadvantage of this method is that there is no guarantee that the organism identified through eDNA analysis actually inhabited or passed through the sampled area, as eDNA can be easily transported by water currents, boats/humans, or even other marine life including predators (Taberlet, Coissac, Hajibabaei, & Rieseberg, 2012).

2.6 Marine mammalogy

2.6.1 Available sensors

Marine mammals are a key environmental receptor considered during the environmental impact assessment process for offshore developments. Marine mammals found in UK waters include a range of dolphin, porpoise, whale, and seal species.

A number of sensor technologies can be applied for monitoring marine mammal behaviour. Several of the methods relevant to fish surveys, including the use of submersible cameras, multibeam echosounders, as well as tagging individuals, can also be applied to marine mammal monitoring (Smith, et al., 2020) (Doksæter, Godø, Olsen, Nøttestad, & Patel, 2009) (Andrews, et al., 2019). (It is worth noting that introducing multibeam echosounders to an already saturated acoustic environment has the potential to affect the behaviour and distribution of marine mammals; this would need to be considered when investigating the relationship between the presence of offshore human activity and marine mammal distribution.)

The fact that many toothed cetaceans such as, dolphin, porpoise and sperm whale species use echolocation for orientation and prey detection also enables the use of passive acoustic monitoring to detect target species. Unlike other survey technologies that involve the active transmission of signals, such as echosounders, and tags with acoustic receivers, passive acoustic monitoring involves the use of recording devices to detect the natural vocalisations generated by marine mammals.

2.6.2 Operating principles

A discussion of the operating principles of submersible cameras, multibeam echosounders and the use of tags in the service of fish surveys is outlined in Section 2.5.2. The same principles apply when employing these technologies in the service of marine mammal surveys (with some practical considerations, such as the tuning of cameras to the infrared spectrum in order to identify warm-blooded, mammalian species). Careful consideration would need to be paid to the welfare requirements in relation to marine mammal tagging, as this is typically restricted on species-by-species basis.

A key component of passive acoustic monitoring surveys is the hydrophone, which operates on the same principles to a microphone, but is designed for underwater applications. Researchers may develop their own systems tailored to the requirements of their study, but commercial solutions also exist. A hydrophone's frequency response (e.g. high-frequency, mid-frequency) is a key consideration of its suitability for a given study, depending on how well aligned this is with the frequency range of a target species' vocalisations. Arrays of hydrophones of a range of frequency responses may be deployed during studies to facilitate both species identification and location prediction (Smith, et al., 2020).

Effective data processing is a critical element of passive acoustic monitoring, as it is necessary to determine the useful signal from unwanted generic noise. The raw waveform data collected during a field study will likely include background noise from the marine environment, flow noise resulting from turbulence as water flows around the hydrophone, as well as potential electrical noise from radio interference etc. (Verfuss, et al., 2018). A successful study will need to isolate the marine mammal vocalisations from this range of noise sources.

Some commercial passive acoustic monitoring solutions, such as C-PODs provide bespoke software packages in addition to the hardware elements in order to facilitate this post-processing of the waveform data and to support species identification. In some cases, these software packages will perform Fourier analyses on the waveform data in order to isolate echolocation clicks that are characteristic of individual species, such as toothed whales and dolphins. (Chelonia, 2022).

2.7 Seabed

2.7.1 Available sensors

The study of water depths and seabed conditions – including terrain, vegetation, and habitat is an important component of marine life monitoring. Researchers can infer data on species population and distribution then use it to make informed decisions regarding offshore infrastructure's impact on marine life. Two principal methods for conducting seabed surveys include capturing high resolution stills or video, and using a sonar system to build an image of the seafloor.

2.7.2 Operating principles

Seabed surveys typically involve a survey vessel. Cameras can be mounted onto submersible frames and towed behind a survey vessel – frames are often bespoke to the seabed environment surveyed. The camera captures still images and video footage of the survey area which is linked to a computer that maps geographical positions of data points. Similarly, in environments of high turbidity, cameras can be mounted vertically in a steel frame with a perspex base, whereby the camera looks vertically down a freshwater tank, enabling clearer imaging of the seabed (Explore the seafloor, 2010).

Additionally, multibeam echo sounders and sonar systems are used to survey the seabed and operate in the same manner (as described above). Multibeam echo sounders, placed on the hull of a ship, provide information on the water depth. ‘Side Scan’ sonar trawled by the survey vessel sends acoustic pings towards the seabed at an angle, objects and terrain on the seafloor cast a shadow, allowing researchers to build an image of the seafloor. The intensity of the returned echoes indicates the material composition of the seabed; dense materials reflect signals with a greater amplitude (Joint Nature Conservation Committee, 2019)

Sonardyne, in collaboration with 3rd parties, have devised a sensor that can remain on the seafloor for up to 10 years and collect bathymetric data. Multiple devices could be installed in an array to collect data on several parameters such as; pressure, temperature, velocity, and seafloor terrain. Data can be retrieved using an ROV or Unmanned Surface Vehicles (USVs), allowing the data to be collected easier and cheaper than before (Sonardyne, 2022).

2.8 Summary of sensor types

Table 1: Summary of Sensor Types

Parameter	Sensor Type	Operating Principle	Offshore Infrastructure Zone	Power requirements	Comms requirements
EMF	Electric field sensor / Magnetometer	Electromagnetism	Immersion	Power is typically supplied by on deck source via tow cable or by battery.	Tow cable can be equipped by two-way communication or transmitted to local host CPU.
Ornithology and Bats	GPS/PTT/GLS Tags	Varies	Atmospheric	Tags are powered by batteries. Solar panel high lithium batteries can be used as a power source. For longer monitoring studies.	In smaller devices, data can be stored on device. Therefore, target species need to be re-caught to download data.

					GPS tags log locations and transmit data to satellites for future retrieval. PTT tag systems require software to decodes messages transmitted from tag to satellite.
	Camera	Optics	Atmospheric	External power supply, ranges between 120-240 VAC	Communication and data access managed via fibre optic, wireless or mobile broadband.
	Radar	Electromagnetism			

Water Quality	Ultraviolet Spectrometry	Spectrometry	Immersion	Spectrometry instruments can be self-powered via rechargeable internal battery, or alternatively powered by an external supply. Variations in power requirements is partly dependent on the mode of retrieval.	Communication via RS-232, or retrieval of data post-deployment using USB.
	Fluorometer	Fluorimetry	Immersion	Fluorometers are usually externally powered (though some may have internal submersible	Data logging is typically carried out via serial connection (though some fluorometers have internal data logging

				batteries for long-term deployment).	which can be accessed via USB or memory card).
Fish	Multibeam Imaging Sonar	Sonar	Immersion	Imaging Sensors are typically powered by a DC supply.	Ethernet or VSDL
	Tags	Varies	Immersion	Battery powered, 3-5 V.	Data is archived on device, alternatively transmissions made to Argos satellite.
Marine Mammals	Passive Acoustic Monitoring	Acoustics	Immersion	Either battery powered (with standard alkaline or lithium cells) or via external power is supply.	Data logged internally on SD card, which can be retrieved post-deployed. Alternatively, communication via ethernet.

Fish/Mammals	Camera	Optics	Immersion	Power supply ranges between 9-30V.	RS232 & RS485 connections
Seabed	Camera	Optics	Immersion	Lithium Polymer Battery	MicroSD Card

3 Regulatory requirements

In order for an offshore infrastructure project to proceed, it is necessary to secure a seabed lease and a marine license. In support of this, it is usually a prerequisite to undertake an Environmental Impact Assessment (EIA) during the development phase (involving the collection of environmental baseline data), and there will often be post-consent monitoring requirements that the developer must also adhere to.

Beyond the licensing considerations relating directly to the infrastructure project itself, it should also be considered whether the subsequent installation of new sensors onto an offshore platform (i.e. following the platform's consenting and commissioning) is deemed to be a licensable activity.

In some cases, the installation of additional sensors onto an operational turbine may be covered by the project's existing marine licence. However, if the relevant licensing body determines that this is not the case (e.g., if the sensor is deemed to be a new deposit on the seabed or in the sea, or if the sensor's construction materials are not listed on the project's marine licence or exceed the permitted headroom for a specified material – for example, an existing marine license may have weight limits on the total amount of steel, plastic fiberglass, carbon fibres etc.), a new marine licence application may be required. Where the latter is the case, the licensing body will have an applicable notice period for new installation applications.

It should be noted that the legislation that determines the specific licensing requirements and application process varies between the devolved regions of the UK. Legislation pertinent to the marine licensing process in the UK includes the Marine and Coastal Access Act 2009, the Planning Act 2008, the Wales Act 2017, and the Marine (Scotland) Act 2010.

Any work conducted in support of the installation of additional sensors will also need to adhere to the offshore infrastructure project's approved Marine Pollution Contingency Plan (MPCP), the Offshore Environmental Management Plan (OEMP), and all dropped object reporting requirements.

It should also be determined whether the installation has the potential to impact a designated European Protected Species (EPS), for example if the installation process disturbs or injures an EPS, or damages or obstructs their breeding or sheltering places. Where this is the case, an EPS mitigation licence application will need to be submitted.

4 Stakeholder engagement

The aims of the second phase of the project were to:

- Develop a stakeholder engagement plan
- Design an interview / questionnaire to engage with identified key stakeholders
- Deliver an interview / questionnaire process

The stakeholder engagement plan was developed in order to identify the primary stakeholders that could influence the opportunity to install environmental monitoring instruments on offshore infrastructure, thereby improving the resolution and frequency of collected data. With the size and scale of the offshore wind industry, there is an extensive supply chain that could have 'influence' across design, installation and operation of offshore wind turbines and their arrays. We have summarised these main groups into the following:

- Original Equipment Manufacturers
- Wind Farm Developers / Operators
- Sensor Manufacturers

Due to the different backgrounds and expertise of these groups, the stakeholder engagement approach was tailored specifically to each group. This is described further in Sections 4.1 to 4.3.

4.1 Original equipment manufacturers (OEMs)

In the offshore wind market, there are a number of primary OEMs providing equipment across the turbine infrastructure. Within the global market there are a number of tiers. Tier 1 manufacturers are large multinational corporations with multiple business units that may be of relevance – including manufacturing and servicing teams. The global market is dominated by Siemens-Gamesa, and MHI Vestas, with GE and others completing the market.

OEMs with significant existing and future market share projections in the UK were approached under the scope of the project to seek their perspective on the potential for increased deployment of environmental monitoring. However, it was not possible to secure their engagement, therefore the input of OEMs is not covered further in this report.

4.2 Wind farm developers and operators

Within the UK wind farm developers manage the development of wind farm projects following successful application at auction sites proposed by The Crown Estate and Crown Estate Scotland. The stages of wind farm lifecycle can be summarised into the following categories:

- Site selection and feasibility
- Scoping and consultation
- Planning application and consenting
- Construction
- Operation and Maintenance (O&M)
- Decommissioning

Developers and Operators have control of wind farm operations and maintenance from the earliest stages in site selection, and they handle significant data, from marine planning, environmental impact assessments, licensing requirements and the operations and scheduled/unscheduled maintenance of the offshore wind farm infrastructure. Their relationship with regulators and environmental stakeholders is key to the practical delivery of environmental monitoring in the offshore wind sector.

4.2.1 Wind farm developer engagement approach

Wind farm developers were approached initially via email to determine their interest in providing input to the project. Following initial engagement, ORE Catapult delivered stakeholder interviews with wind farm developers and operators EDF Renewables and Orsted.

The stakeholder interview questionnaire for wind farm developers was focussed around the following topics (a copy of interview questions can be found in Appendix 1):

- Prioritisation of offshore wind operations
- Primary logistical consideration of installation of sensors during operations
- Existing environmental and biological monitoring devices
- Platforms of convenience

4.2.2 Prioritisation of windfarm operations

During the stakeholder engagement process, the developers noted that from an asset life management perspective, the ongoing condition monitoring of wind turbines is critical for ensuring the long-term stability, service life and optimal production of energy across the offshore wind farm. With regards to environmental impacts, the developers separately agreed that mandatory environmental monitoring requirements stipulated by their licensing and consent conditions are of particular high importance.

It was noted that, where there are not mandatory requirements around environmental or biological monitoring, the developers will consider requests for additional monitoring on a case-by-case basis. Where there is an opportunity to enhance monitoring in relation to a specific objective, such as an acceleration of the consenting process, or to mitigate against potential objections, the developers reflected that there would very likely be a willingness to engage. Additionally, they noted that they would likely be open to exploring additional monitoring where this presented an opportunity to contribute to, and improve, the overall understanding of the influence of offshore wind development on the marine environment.

4.2.3 Primary logistical consideration of installation of sensors during operations

The developers noted that there would likely be complexity and risk with regards to the installation of sensors after the construction phase has been completed. They agreed that the ideal scenario would be to incorporate environmental monitoring sensors on the asset at the design phase, before construction is underway and the wind farm becomes enters the operational phase. For instance, the installation of additional sensors in or around the splash zone can be very challenging in an operational environment when there are multiple considerations including sea swell, vessel availability, time to install etc., which all impact the on health and safety of the technicians in the field. It was also noted that there would be certain stages of the construction phase when sensor installation would be challenging due to resource availability and the many parallel activities taking place across the offshore wind farm, therefore it would need to be carefully planned in advance.

Despite the preference for the integration of additional sensors as early in the windfarm lifecycle as possible, it was noted that certain considerations could make this challenging to achieve in practice. It was anticipated that in order to integrate additional sensors into the turbine at the design stage, this would require a strong case for intervention to be presented to the turbine OEMs. Sensor integration during the installation phase would also be expected to present challenges due to time constraints and limited personnel resourcing.

Offshore Wind Technicians also require the relevant qualifications for working offshore, and their training which must be accredited by the Global Wind Organisation (GWO). Additionally for all offshore operations there is a significant amount of planning and organisation to ensure that everything will be orchestrated in a way to minimise risk and fully consider health and safety implications. This includes gaining an understanding of the equipment sizing, Data Acquisition (DAQ) systems and storage requirements, as well as communications and cyber security considerations. None of these factors are insurmountable, but they must be considered when reviewing the case for intervention for additional environmental monitoring.

With regards to the overall cost of additional sensor installations (and any related decommissioning), this will be partly dependent on the relevant vessel and technician day rates, equipment costs, turbine downtime costs (if the installation is taking place during the operational phase, and the turbine needs to be shut down to facilitate this), as well as additional support functions necessary as part of the planning for the installation of the sensors. Where the sensors are required as part of the wind farm's marine licence conditions, then it is expected that the wind farm developers will bear these costs. However, if additional environmental monitoring sensors are being installed to support wider (potentially voluntary) initiatives, then further clarity would be required as to who would sustain those additional costs.

Operators were also asked to consider an operational wind turbine and describe how the 'ease' of installation would vary across the infrastructure. All operators were in agreement that the atmospheric zone would be the easiest to plan and deliver. Primary locations for environmental sensors would include the nacelle, transition piece and the tower, which should not have a significant impact on routine operations.

Within the benthic region, developers proposed that it may be easier to place sensors on the seabed close to the turbine foundation rather than on the foundations themselves. This could potentially reduce the risk of the development of biofouling, but this is likely to be considered on a case-by-case basis, based on the wind farm's environmental characteristics and physical location.

The cost of installing in the splash zone or water column is likely to be relatively similar due to the need to mobilise a vessel in conjunction with an ROV. Again this would be dependent on the final position of the sensor, but this was the general approach favoured by the operators.

4.2.4 Existing environmental sensors on offshore wind farm developments

In addition to the wind resource and metocean sensors that are installed across wind farm infrastructure (e.g. wind speed, direction, temperature, wave height etc.), wind farm developers will be required to install additional sensors to monitor environmental parameters in accordance with their marine licence conditions. For example, this could include acoustic monitoring undertaken to manage the impacts of certain activities, particularly during the construction phases of wind farm (e.g. piling and drilling), or bird monitoring sensors used to determine ornithological impacts. While these are deployed fundamentally to meet license conditions, it was noted that developers benefit additionally from this by gaining further insight into the environment within which they are operating.

From a developer's perspective, the UK Government's ambitions and continued support for the offshore wind sector indicates that there will a dependable pipeline of projects available to tender for into the future. However, it is recognised that the consenting time required for new offshore wind developments presents a key challenge. The wind farm developers therefore expressed support in principle for increasing environmental monitoring if this was linked to a clear process in which the consultation and consenting phase could be accelerated. Additionally, as more data is collected at wind farms, it would be beneficial if there was an opportunity for the growing collection of environmental datasets to be used to support the consenting of future wind farms (for example, if this could be used to increase the shared understanding of recoverability of certain habitats such as Special Areas of Conservation (SACs)).

4.2.5 Platforms of convenience

When interviewing the wind farm developers, the concept of 'platforms of convenience' was proposed. In principle, given the projected growth of the offshore wind industry and wider offshore energy sector, there is an opportunity to utilise assets across the UK's waters to support the monitoring of specific environmental and biological parameters to better understand the impacts of offshore energy installations on the wider environment, and to give key stakeholders a better understanding of how environmental parameters might evolve over time, potentially providing data in real time.

The developers interviewed as part of this project showed a willingness to explore this concept in further detail. It was noted that the expected benefits would need to be clear from the outset, and that the discussion would need to factor in the considerations outlined above.

4.3 Sensor manufacturer engagement

To support the technical engagement process with the sensor manufacturers and experts, a separate questionnaire (included in the Appendix) was developed that was tailored to their specific experience and expertise, while trying to maintain a consistent approach with the process of engagement undertaken with the wind farm developers. The questions were designed to effectively reflect the main considerations, implications, and benefits of using offshore wind infrastructure for environmental monitoring.

4.4 Sensor manufacturer interview results

The following sub-sections summarise the outputs captured during discussions with sensor manufacturers, grouped by the environmental parameters: electromagnetic fields, ornithology and bats, water quality, and marine mammals. The following organisations accepted invitations to engage with the project (NB it was not possible to secure the input from sensor experts specialising in every environmental parameter, hence fish and water quality are not included within this section):

- Geomatrix Earth Science Ltd
- DeTect
- MOTUS Telemetry
- AML Oceanographic
- Chelonia

4.4.1 Electromagnetic fields

Manufacturers engaged with agreed there may be some benefits to using offshore assets to host EMF monitoring equipment, however, it was highlighted that the surrounding infrastructure may influence data collected by the instrument. Magnetometers are highly sensitive, therefore a greater separation of the sensor and turbine is preferable to accurately determine EMF strengths in the water column. In order to counteract external influences, it was proposed that the background fields around power cables could potentially be compensated; a magnetometer could be installed to take background measurements, whilst another magnetometer would measure the field from the radiating cable. The measurements would then be compensated against each other, to measure the parameter if there were no external influences. This type of set-up is typical in areas where isolation is not an option, however it is difficult to implement and adds additional complexity to monitoring. Stakeholders were unable to provide further comment on the application of magnetometers onto fixed infrastructure without further knowledge of the specific details of the deployment.

4.4.2 Ornithology and bats

Offshore avian monitoring systems are commercially available and are currently supplied to offshore wind farms. These systems typically consist of an integrated camera and radar, installed on the atmospheric zone of wind turbines (typically on the transition piece of the turbine in order to allow technicians' access for maintenance and servicing).

Camera and radar configurations are considered reliable in adverse weather and can provide long-range detection of target species' movement both at night and during poor visibility. Both power and communication can be supplied directly from wind turbine, with the power supplied directly from wind turbine power connections and two-way communications streamed via the wind farm's fibre optic links to the onshore network. In terms of maintenance, these monitoring systems are fairly robust and require minimal upkeep, with cameras typically requiring general cleaning twice a year.

Camera and radar can also be configured to allow the radar to guide the camera to a target species, with the footage captured used for species classification. It was noted that automated classification of species is limited, however work on this is in early development. Additionally, innovative software has recently been developed which can communicate with wind farm's Supervisory Control and Data Acquisition (SCADA) system for real-time risk mitigation. Upon detection of an oncoming target species from the radar, this is communicated to the wind farm's SCADA system, which can automatically apply an appropriate mitigation measure, such as idling the turbine rotor until the risk passes (although it should be noted that deployment of this solution has been limited to date).

In terms of the logistical considerations of installing the equipment, it was considered that these would be comparable to the general challenges faced when working offshore. Sensor manufacturers would be required to work with developers and appropriate engineers to facilitate the deployment onto existing infrastructure and integration with offshore control systems.

Similarly to camera and radars, electronic receiver stations can be installed on wind turbines to record uniquely coded signals detected from radio transmitters tagged to birds and bats. The role of MOTUS Telemetry, an existing automated radio telemetry network of radio transmitters and receivers, was highlighted. The transmitters and receivers used in the MOTUS network will not interact with other monitoring devices (such as GLS, PTT and GPS), and offshore wind infrastructure was thought to offer a promising opportunity to expand the existing network of receiver stations. The addition of receives onto offshore turbines was expected to be straightforward to implement, and, once the receivers are installed, they should be able to detect the existing transmitters in circulation. This data can either be collected post-deployment, or through connection to the wind farm's data network. Additional information on MOTUS Telemetry can be found here: Motus Wildlife Tracking System

4.4.3 Water quality

Water quality instruments are commonly used for the purpose of marine environmental monitoring, such as baseline surveys for wind farm developments. The instruments are typically buoy-mounted, or deployed on seabed landers, however it was noted that offshore wind infrastructure could provide an opportunity for the deployment in the future.

Instruments are typically equipped with a single water-proof connector for both power and data streaming, and communication with the instrument is carried out by an on-board computer, using a terminal emulator. Additionally, devices may contain internal hardware to support internal datalogging and power, thereby bypassing the need for a connector.

The impact of biofouling on sensor performance was raised. One mitigation involves the use of a UV light source, which can either be fully integrated, or clamped onto the sensor guards to illuminate sensor heads, thereby preventing marine growth without causing any contamination or harm to the marine environment. These UV light solutions typically have low power demands and an approximate operational life of 1.5 years, depending on its duty cycle. Therefore, retrieval of the instruments would be required to facilitate the replacement of the UV light source; however this would ensure that the data quality is maintained over longer-term deployments, without having to service and clean the instrument more frequently. To facilitate this preventative maintenance, and reduce operational risk, it was suggested that a bespoke frame could be designed to enable the deployment and suspension (and subsequent recovery) of the sensors from the turbine's transition piece.

It was also highlighted that as water quality sensors accurately log the data relative to the position of their deployment, an array of multiple instruments may be required to sufficiently monitor a specified environment. This applies for both the lateral and vertical axis, as parameters can vary at different locations and/or depths.

4.4.4 Marine mammals

Commercially available solutions currently exist to support the long-term acoustic monitoring of marine mammals. The POD acoustic monitoring solutions developed by Chelonia have been deployed globally for this purpose (for example, earlier forms of the POD were deployed for monitoring the effects of fixed offshore turbines at several windfarms in Denmark, during which instruments were moored independently of the turbine structure (Teilmann, Carstensen, Skov, & Henrikson, 2002)).

It was advised that, acoustic monitoring devices are usually moored at a regular spacing to macro-level view of marine mammal behaviour (rather than a localised analysis at each turbine). Spacings of 25-50km should provide adequate data to represent the ecosystem, therefore it would not be necessary to attach pods to adjacent wind turbine within an array. Chelonia's POD solution typically requires less than two hours of servicing work annually.

It was considered that offshore wind infrastructure could offer a suitable opportunity for acoustic monitoring deployment and could potentially make a valuable contribution to the seasonal and long-term monitoring of key marine mammal populations.

It was suggested that a line or rope could be used to attach an acoustic monitoring device to a wind turbine platform, and that similar set-ups have been used for POD devices on oilrigs successfully to support offshore monitoring. However, this would likely require some form of protection to mitigate against the device striking the turbine foundation due to hydrodynamic conditions. Alternatively, it was proposed that a bespoke frame could potentially be used to rigidly fix the acoustic monitoring device to a turbine's foundation, although further engagement with wind farm developers would be required to design any potential solutions in this regard.

In terms of data requirements, PODs utilise an SD card which can be retrieved during maintenance of the device, and bespoke PC software is currently used to analyse the data. Currently, the volumes of data and low power constraints prevent continuous streaming to shore; solutions to facilitate this are currently being explored, although at the time of writing they are not close to market. For power requirements, PODs utilise alkaline 10 D-Cells which require replacing three times per year if used continuously. Primary lithium cells may also be employed.

The potential effects of kelp and other marine growth on the turbine foundations was also highlighted. Kelps normally grow on hard substrate, such as on rock armour, which can be used to prevent scouring around the monopile foundation. This interaction changes the local ecology and may attract more marine mammals (and other predators) to the site. From an environmental monitoring perspective, if rock armour is present, this may present challenges when defining the local ecology of the site, as any data collected may be affected by the gradual accumulation of marine growth, potentially over a number of years (after which the growth of kelps and other marine life may be a stable component of the local ecosystem). Sensors could be installed during a wind farm's commissioning in order to monitor the evolving interaction between biofouling and marine mammal attraction, and the potential impacts in the local marine mammal population behaviour.

5 Sensor impact assessment

This chapter reflects on the outcomes from both the technical review and stakeholder engagement chapters of the report in order to assess the potential suitability of the various sensor types with regards to their installation on infrastructure.

5.1 Electromagnetic fields

In principle, there is nothing to prevent EMF sensors being installed onto existing offshore infrastructure, however the utility of this depends on the purpose of the monitoring. If the principal aim is to obtain baseline measurements of background EMF levels at defined locations in the sea, then installing sensors on fixed infrastructure could potentially meet this requirement (understanding that the offshore infrastructure, depending on its function, may also act as a source of EMF emissions).

However, there are other objectives to subsea EMF surveys that would not be met by the installation of sensors on fixed infrastructure. For instance, a crucial area of interest relates to the current lack of understanding concerning the potential impact of EMF emissions from offshore wind farm inter-array cables on a range of electro-receptive marine species (Marine Scotland, 2022).

In order to understand these impacts, it is necessary to obtain operational monitoring data of EMF emissions along the cable route, as well as behaviour and population data of key electro-receptive species within the vicinity of the cable routes, and to compare this data against pre-installation baseline data. To understand the distribution of these EMF emissions (i.e. the relationship between field strength and distance from the cable), it is necessary to undertake mobile surveys.

To obtain this magnetic field distribution data, electric and magnetic field sensors have been installed on ROVs (remote operating vehicles) and AUVs (autonomous underwater vehicles) so that measurements can be taken along the cable route (Dhanak, et al., 2015). Other approaches have involved towing purpose-built sensors behind slow moving vessels along cable routes (Hutchison Z. L., Gill, Sigray, He, & King, 2020).

With these considerations in mind, it is clear that while electric and magnetic field sensors could be installed on fixed offshore infrastructure, the researchers leading the monitoring study would need to determine the relative benefits in relation to their aims, and the consideration that mobile methods may yield more useful results. It is important to note that there is difficulty with attributing the behavioural or distribution of electro sensitive species in the water column to actual EMF emissions. Behavioural changes could be the direct result of the presence of cables themselves, along with changes to seabed structure through cable installation and cable protection.

5.2 Ornithology and bats

In recent years, studies and private companies have used image recognition software in conjunction with radar to monitor birds and bats in the vicinity of turbines, both on and offshore. Sensor developers are seeking to provide solutions to address the significant knowledge gaps in respect of bird and bat interactions with offshore wind infrastructure by developing advanced camera and radar technologies to mitigate collision risk. Using offshore infrastructure as a platform for monitoring a wide range of parameters therefore has the potential to support current ornithology research efforts.

It is important that both the camera and radar are reliable in adverse weather, that they can be positioned so that interference from the turbine blades is limited, that they offer long-range detection capabilities, as well as an even detection probability across the entire monitored range.

The UK Marine Strategy has identified gaps in the monitoring of high priority species, as well as the need for greater coverage of sea data collection (Defra, 2019) (current Good Environmental Standards (GES) assessments are based on data from the seabird monitoring programme, The Wetland Bird Survey (WeBS), periodic bird surveys and volunteer surveyors at sea). Adding bird monitoring sensors to infrastructure could therefore improve geographic coverage and give more consistent recording over time.

The use of cameras and radars on offshore infrastructure has been deployed successfully through research initiatives such as The Offshore Renewables Joint Industry Programme (ORJIP) bird collision avoidance study which implemented innovative technology to monitor the behaviour of birds around wind farms. An advantage of using cameras is that species can be identified through expert visual analysis. Automated identification of species is fairly limited, however, based on current technological advancements of avian monitoring systems and artificial intelligence, automated identification could be realised in the coming years. Such real time identification of birds and bats would contribute significantly to environmental monitoring. Additionally, advances in the monitoring of birds and bats could support the identification of endangered species (thereby enabling appropriate mitigation measures to be put in place to limit the risk of collision), as well as the identification and verification of potential collisions with the turbine rotors.

5.3 Water quality

Spectrometers and Fluorometers are typically installed on remotely operated vehicles or operated by divers in order to obtain measurements (Valeport, 2022) (Sea Bird Scientific, 2022). Examples of their installation onto pre-existing offshore infrastructure were not encountered during the course of this project, however there is nothing to prevent this from happening in principle.

The UK Marine Strategy currently describes the use of Continuous Plankton Records (CPR) and fixed point sampling for pelagic habitats to address Descriptor 1: Biodiversity and Descriptor 4: Food Webs (Defra, 2019). The installation of water quality sensors including spectrometers, fluorometers and CPR on offshore infrastructure could therefore provide an opportunity to support existing environmental records to help to facilitate the achievement of the GES descriptors.

However, the potential requirement for multiple sensors to be deployed at a given wind turbine should be considered. Depending on the scope of the environmental study, and given the short range of these sensors, several sensors may need to be deployed at different depths. With this in mind, the deployment of multiple spectrometers and fluorometers on offshore infrastructure could potentially prove to be a costly alternative relative to the use of mobile surveys using ROVs. One mitigation may involve the installation of spectrometers and fluorometers into multi-parameter instruments alongside other sensor types to facilitate simultaneous measurements, however, there nevertheless remain some potential challenges in relation to the use of offshore infrastructure for hosting water quality monitoring which will need to be considered.

5.4 Marine mammals

In principle, it should be possible to attach passive acoustic monitoring sensors onto offshore infrastructure, and passive acoustic monitoring devices are currently deployed for long-term environmental monitoring on wind farms. The pods are typically moored mid-way between each turbine, however there is scope for pods to be attached directly to, or mounted onto, offshore infrastructure.

A key consideration is the ease of access to the devices for servicing, maintenance, and data retrieval, therefore a suitable platform to deploy the sensor from is important. While internal power and data storage supports the long-term deployment of these sensors, there is however an element of risk, as equipment failure would only be identified post-deployment. Therefore, regular servicing trips may be required to maintain the functionality of the device, which could prove costly if it was difficult to access. Researchers leading a marine mammal monitoring programme would need to confirm whether the positioning of the infrastructure would meet the requirements of their study.

It would also be necessary to determine whether mechanical noise emitted by the infrastructure could be successfully isolated during the data processing phase. For example, in the case of an offshore wind turbine, potential noise sources might include the rotor, drivetrain and yaw drives, as well as wave-structure interactions at the water surface level, underwater turbulence effects, and potential electrical interference. Data collected on background noise could be contributed to the Marine Noise Registry (available here: Marine Noise Registry (jncc.gov.uk)) which is used to inform management measures and conservation advice. There are some current knowledge gaps associated with the noise emissions produced during the commissioning, operation and de-commissioning of a wind farm (particularly for floating offshore wind), therefore monitoring background noise could contribute to addressing this issue.

It should also be noted that marine mammal detection performance improves with the concurrent use of multiple methods (Smith, et al., 2020). Therefore, while fixed infrastructure provides the opportunity to establish fixed monitoring points for the purposes of passive acoustic monitoring, in order to deliver the most accurate possible analysis of marine mammal population and behaviour data, the importance of additional methods should not be overlooked. For instance, digital aerial surveys play a key role in determining the density and/or abundance of marine mammal populations. Visual recording methods should be considered in conjunction with acoustic data of marine mammals for an enhanced analysis of a given environment. With these factors in mind, consideration should be given to the potential for fixed infrastructure monitoring points to play a role within a larger suite of marine mammal monitoring methodologies.

The UK Marine Strategy highlights insufficient data on cetacean abundance and distribution due to infrequent surveys. Regional acoustic detection programmes are currently used in order to address this, however the deployment of additional sensors on offshore infrastructure could potentially expand the scope of existing environmental surveys.

5.5 Fish

Monitoring of fish populations utilises a range of methodologies, some of which could be supported in principle through the use of offshore infrastructure. While submersible cameras are regularly operated by divers or ROVs, they could nevertheless be installed on offshore assets to provide continuous monitoring, although this would of course come at the cost of the mobility offered by other methods.

In the case of fish tagging, there are a number of approaches by which the data is recorded. Some methods are unlikely to meaningfully benefit from the use of offshore infrastructure, including those that rely on recapturing the tagged fish in order to collect the data from the tag, as well as the use of tags that transmit their data to satellites. However, in the case of acoustic telemetry, there would be an opportunity to use offshore infrastructure to host the acoustic receivers that record the data transmitted from compatible tags. Acoustic receivers do not necessarily need to be attached to existing infrastructure and can be placed directly onto the sea floor, (Marine Conservation Society, 2022), however there are some existing examples of studies that used existing infrastructure in rivers to host acoustic receivers (Steig, 1999), indicating that a similar approach could be adopted for offshore monitoring.

There is limited operational experience surrounding eDNA analysis, particularly in terms of its suitability to be deployed from offshore infrastructure. Emerging research involving the use of eDNA to support environmental monitoring at the Blyth Offshore Wind Demonstrator project (Renews, 2022) should be monitored closely to determine whether lessons learned could applied to the question of using offshore assets to support eDNA monitoring.

Unfortunately, it was not possible to secure the input of subject matter experts on the topic of fish monitoring. Therefore further engagement on this topic would be beneficial in order to corroborate the above findings and to inform future actions.

5.6 Seabed

There are a number of operational concerns that may limit the utility of using offshore infrastructure to support seabed monitoring.

Principally, the inherent location of seabed monitoring presents certain challenges. If sensors, such as submersible cameras or sonar systems, were to be successfully incorporated into an offshore asset at the design stage, there is a significant chance that activities undertaken during the installation of the structure (such as pile driving, or drilling) could cause significant damage to those monitoring systems. On the other hand, if a seabed monitoring system was to be retrofitted onto the structure during the operational phase, the practical challenges of attaching a sensor to a structure in the vicinity of the seabed touchdown point may well negate any potential benefits, relative to more conventional seabed monitoring approaches.

Of course, certain seabed monitoring approaches are mobile by nature (such as multibeam echosounders deployed from survey vessels, and submersible cameras installed on ROVs or operated by divers). It would therefore also need to be considered whether the static nature of offshore infrastructure would limit the value of these monitoring approaches.

6 Conclusions and recommendations

The current rate of deployment of offshore wind assets provides a potentially significant opportunity to expand the current scope of offshore environmental monitoring. Through a technical review process and engagement with relevant technical stakeholders, this report has explored the potential use of offshore infrastructure to support environmental monitoring in relation to the following parameters: electromagnetic fields, ornithology and bats, water quality, marine mammals, fish and seabed.

Engagement with wind farm developers indicated that they would be open in principle to the opportunity of using their offshore assets to host additional environmental monitoring sensors. It was however noted that a clear understanding of the objectives would be required in order to justify the case for expanding upon the current levels of environmental monitoring that already takes place across offshore wind farms.

Wind farm developers noted that they already host environmental monitoring sensors in accordance with their marine licence conditions. However, if it could be demonstrated that an expansion of this monitoring could help to reduce the consenting time for offshore wind farms by providing a greater understanding of the impacts of offshore wind infrastructure on the local marine environment, then this could support the case for installing additional environmental sensors. Further, it was noted that if an understanding of the potential environmental impacts of offshore wind could be enhanced, it should allow wind farm developers and operators to mitigate more effectively against potential negative impacts.

Wind farm developers did note that a greater understanding would be required of the potential roles and responsibilities if environmental monitoring within offshore wind farms was to be increased beyond the levels required by marine licence conditions. Further clarity would be required regarding who would bear the costs of the installation, maintenance, and decommissioning of the additional sensors, and who would be responsible for their operation. It was generally accepted that the incorporation of additional sensors at the design stage of the wind farm would be preferable to their retrospective installation onto operational turbines, although a number of challenges were highlighted, and retrospective installation should also be possible.

Engagement with sensor manufacturers and experts indicated that the utilisation of offshore infrastructure could present a promising opportunity to support additional environmental monitoring, at least in respect of certain environmental parameters. Feedback suggested that the monitoring of ornithology, bats, marine mammals, and fish could likely benefit from this approach, and further investigation would help to determine the specific practical requirements, as well as risks and opportunities in relation to this. In the case of other environmental parameters, notably EMFs and water quality, a number of challenges were identified that may limit the utility of installing these sensors onto offshore infrastructure, and it was less clear if benefits could be realised above and beyond existing survey methodologies.

While it would be necessary to determine a monitoring project's power and communications requirements on a case-by-case basis, it was generally agreed that offshore wind turbines are likely to provide the appropriate connections, where these are required (noting that some sensor designs utilise internal batteries and data storage and could therefore operate independently of the wind farm's network).

There was some uncertainty regarding the mechanism by which the sensors would be fixed onto offshore assets, particularly where they would be installed underwater, and that a more detailed understanding of the scope of a specific environmental study, and the relevant wind farm components, would be required in order to comment further. Similarly, without these specific details, sensor manufacturers were unable to provide more precise guidance on potential deployment costs and logistical challenges. Therefore, collaborative engagement between wind farm developers, sensor manufacturers, advisers and regulators would be required on a case-by-case basis to address these uncertainties. It is likely that, at least in certain cases, targeted design work may be required to facilitate the safe and efficient installation (and subsequent retrieval) of sensors onto offshore infrastructure.

Further investigation would be required to understand how the infrastructure itself, and the interaction of the infrastructure with the external environment, may influence a particular monitoring programme. It will be important to consider the potential sources and extent of these influences in order to support the integrity of the environmental data collected.

Testing and validation would likely be beneficial for demonstrating the suitability of using offshore assets to support wider environmental monitoring. Testing sensors on demonstrator offshore wind turbines, as well as commercial offshore wind farms, would help to verify their suitability for fixed infrastructure and would enable any necessary adaptations to be made prior to long-term deployment, thereby ensuring the success of future applications and cutting overall costs in the long-term. It is also important to note that relevant innovations, such as automated image recognition, are currently undergoing development and have the potential to further enhance environmental monitoring offshore.

To conclude, this project has identified that there are opportunities for using existing and future offshore infrastructure to support wider offshore environmental monitoring. The nature and scale of the opportunity varies on receptor-by-receptor basis, and in many cases further work would be required to address existing practical challenges and uncertainties. Collaboration between regulators, key environmental stakeholders, wind farm developers, and sensor manufacturers will be key to addressing these challenges.

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Appendices

1.1 Stakeholder Engagement Questionnaire – Windfarm Developer/Operator

Organisation name	N A M E
Location of head office	*Address*
Country of Operation	
Location of manufacturing site (if appropriate)	*Address or coordinates?*
Direct contact	
Industry Role	• Developer • Owner/Operator • OEM • Manufacturer • Fabricator • Government
Role within organisation	• Engineer • Technician • Designer • Analyst • Management • Policy Advisor

For your organisation:	Role within offshore wind …… What is your organisations ambitions for Net Zero (feel free to link rather than respond if there is information that can be obtained elsewhere) Where possible give details of action plans and opportunities Organisations role in the selection and placement of sensors on installed offshore assets
Ranking each of the following from - lower priority 1 – 5 higher priority with respect to wind farm operation	• Condition monitoring of assets • Environmental monitoring around assets • Environmental Impact assessments during operations • Ability to carry out remote monitoring of assets • Improved monitoring of environment, and temporal and spatial resolution of data collected • Improving the ability to monitor fish/mammals/birds in and around the wind farm infrastructure • Improving ability to monitor seabed and habitats across the water column • increase certainty in levels of impact for the consenting process
Technical Questions relating to sensor retrofitting	Due diligence required before installing any additional sensors What are the primary logistical challenges and resources that would be required to around retrofitting sensors across the turbine infrastructure Costs of sensor/comms deployment in benthic / water column / splash zone / aerial zone

	Ease or difficulty of sensor replacement in benthic / water column / splash zone / aerial zone wrt: • Costs • Logistics • Communications • Data Access / Security • Storage • Powering
What oceanographic / biologically centric sensors are already deployed on your wind farm? Additionally, are you aware of any other sites already collecting data using oceanographic / biologically centric sensors?	Written response
What are the primary O&M / logistical challenges around sensor deployment and replacement across the turbine infrastructure	• Height • Resource availability • Vessel • Confined spaces • Admin (record of sensors)
How could the implementation of environmental sensors across an offshore wind farm array enhance understanding of	

impacts (positive and negative) of the offshore wind farm. As a follow up, where do you see the biggest opportunities to deploy this technology to support futher offshore wind development	
Would you anticipate additional sensors having an impact on the existing seabed lease (Developers / Owners / TCE / CES	
Finally, what would your appetite be to host long term data collection through 'platforms of convenience' to capture key environmental, benthic, and biological data in and around the wind farm. In this example, we envisage a 'platform of convenience' as a met mast, turbine or substation where sensors installed would be operated and maintained by a 3rd party in collaboration with the operator.	

1.2 Stakeholder Engagement Questionnaire – Sensor Manufacturer

Organisation name	
Location of head office	
Location of manufacturing site (if appropriate)	
Direct contact	
Can you foresee any logistical challenges that would be required to retrofit sensors across the turbine?	
Are you able to comment on the ease or difficulty of sensor replacement in benthic/ water column/ splash zone/ aerial zone wrt; Communications Data Access/ Security Data Storage	

Powering Logistics	
Windfarms are arranged in arrays with spacing of (7 x rotor diameter). Typically existing and future wind farms have a rotor diameter of 100- 200m. With this in mind, would offshore wind infrastructure provide a suitable opportunity to enhance environmental monitoring?	
Do you currently supply sensors to offshore windfarms, or aware of other manufacturers supplying sensors to offshore wind?	

Are you able to provide indicative costs of sensor/comms deployment in benthic/ water column/ splash zone/aerial zone?	
Finally, what is your view on the potential utility of facilitating long term data collection through ‘platforms of convenience’ to capture key environmental, benthic, and biological data in and around the wind farm. In this example, we envisage a ‘platform of convenience’ as a met mast, turbine or substation where sensors installed would be operated and maintained by a 3rd party in	

collaboration with the operator.	

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Catalogue code: NECR446

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