WEDUSEA

A step change for wave energy

Deliverable 2.8

Complete Environmental Monitoring Plan

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Acronyms

Acronym	Description
ADCP	Acoustic doppler current profiler
DAQ	Data acquisition system
EMEC	European Marine Energy Centre
EPS	European Protected Species
FAD	Fish aggregating device
FEEDPP	Front end engineering design and pre-procurement
GPS	Global positioning system
IEC	International Electrotechnical Commission
IMPAQCT	Integrated Metocean Processing and Quality Control
LCOE	Levelised cost of energy
MREC	Marine renewable energy converter
OE	Ocean Energy Ltd
OES	Ocean Energy Systems
ORJIP	Offshore Renewables Joint Industry Programme
OWC	Oscillating water column
PAM	Passive acoustic monitoring
PPA	Power performance assessment
PSD	Power spectral density
SCADA	Supervisory, Control and Data Acquisition
SEA Wave	Strategic Environmental Assessment of Wave energy technologies
SPA	Special Protection Area
SPL	Sound pressure level
TOL	Third-octave band level
TRL	Technology readiness level
UAV	Unmanned aerial vehicle
UCC	University College Cork
WEC	Wave energy converter
WEDUSEA	Wave Energy Demonstration at Utility Scale to Enable Arrays
WP	Work package

1 Introduction

1.1 WEDUSEA Project Summary

Ensuring Europe and the United Kingdom (UK) meets energy transition targets to a low-carbon economy by 2050 requires the rapid acceleration of marine renewable energy technology development in a cost-competitive manner. The WEDUSEA (Wave Energy Demonstration at Utility Scale to Enable Arrays) project has been established to demonstrate a large-scale wave energy converter (WEC) in real sea conditions, advancing performance, availability and reliability through extended testing and contributing to a 32% reduction in the levelised cost of energy (LCOE) of the technology from €361 per megawatt hour to €245/MWh. Co-funded by the EU Horizon Europe Programme and Innovate UK, the project partnership consists of 14 participants spanning industry and academia and is being coordinated by Irish wave energy developer Ocean Energy (OE). Ocean Energy have been developing their "OE Buoy" WEC concept over nearly 20 years, progressing to technology readiness level (TRL) 6 with a demonstration of a 500 kilowatt device at the US Navy Wave Energy Test Site.

The concept for the WEDUSEA project is to enable future array deployment and will take the learnings from the construction and operation of OE's 500kW device at WETS and apply these to the OE35 1 MW machine in an operational environment. The OE35 device will be demonstrated at the European Marine Energy Centre's (EMEC) grid-connected wave energy test site at Billia Croo, west of Orkney. Rigorous technical and environmental demonstration, following international standards, will occur over a 2-year period in Atlantic wave conditions with outcomes directly impacting policy, technical standards, public perception, and investor confidence. The WEDUSEA project aims to demonstrate that the technology is on a cost reduction trajectory in line with EU Strategic Energy Technology Plan targets and will support the pathway to commercial array scale.

1.1.1 Environmental scope and deliverables

The project aims to progress knowledge on environmental impacts associated with WEC development through the following objective:

- The gathering of a comprehensive set of environmental data during this extended deployment through the use of best practices and applying recognised standards. This is one of the first such opportunities for extended environmental monitoring to be undertaken around a deployed device at a wave energy test site. The data will be used to inform the next edition of the State of the Science produced by the Ocean Energy Systems (OES) Environmental initiative. It will also provide regulators with better data and models to reduce the uncertainty around the environmental impacts of wave energy.

Work Package (WP) 7 of the WEDUSEA project will include a programme of environmental monitoring that will be undertaken during months 24-47 of the project, in line with the demonstration of the OE35 device WEC at the Billia Croo test site during this period. Environmental monitoring activities will inform uncertainties around potential environmental impacts of wave energy, as well as contribute understanding on emerging research themes surrounding the scaling up from a single device to array.

The following focus areas will be addressed in the environmental monitoring programme:

- Underwater and airborne noise generated by the OE35 device and potential impact on marine vocalising species.
- Linkages between fish aggregation and hydrodynamics around the OE35 device.

- Seabird interactions with the OE35 device and nearby waters, and potential influences on predator-prey dynamics driven by fish presence (linked with the above).
- Impact of energy extraction on ocean and coastal dynamics scaled up to a hypothetical array.
- Development of guidance for data management, integration, and analyses.

Work Package 2 of the project encompasses several Front End Engineering Design and Pre-Procurement (FEEDPP) activities, in which the design of the environmental monitoring programme is being conducted under Task 2.8 of WP2 and in collaboration with partners OE and University College Cork (UCC).

1.2 Aim of the report

This report forms deliverable D2.8 Complete Environmental Monitoring Plan, the aim of which is to present the scope of environmental monitoring that will be conducted over the course of the WEDUSEA project. Key potential environmental impacts likely to be associated with the OE35 device will be identified to inform monitoring activities, from which topic-specific plans will be presented which include the approach to data collection, proposed equipment, and data processing.

2 Test site and device description

2.1 Billia Croo wave test site

The Billia Croo full scale grid-connected wave test site is located off the west coast of Mainland, Orkney (Figure 2). The site sits to the north of Hoy Mouth, the western entrance to Scapa Flow. Subjected to the powerful forces of the North Atlantic Ocean, Billia Croo is an area with one of the highest wave energy potentials in Europe with an average significant wave height of 2 – 3 metres. The site consists of five cabled test berths in up to 70m water depth (four situated at 50m, the fifth at around 70m), located approximately 2 kilometers offshore and 0.5km apart. The five 11 kilovolt subsea cables feed into the EMEC substation which houses the main switchgear, backup generator and communications room, and has been carefully designed to minimise visual impact.

Three Datawell Directional Waverider MkIII buoys are located on site which continuously measure sea state parameters (maximum wave height, significant wave height, energy period and peak direction) as well as their Global Positioning System (GPS) position and sea surface temperature. A purpose-built onshore weather station provides real-time meteorological data for the site. This data is fed into EMEC's Supervisory, Control and Data Acquisition (SCADA) system, with live data feeds on the wave and meteorological conditions. The SCADA system incorporates a drift alarm for each buoy, utilising the GPS information.

The OE35 device shall be deployed at berth 5 (Figure 1).

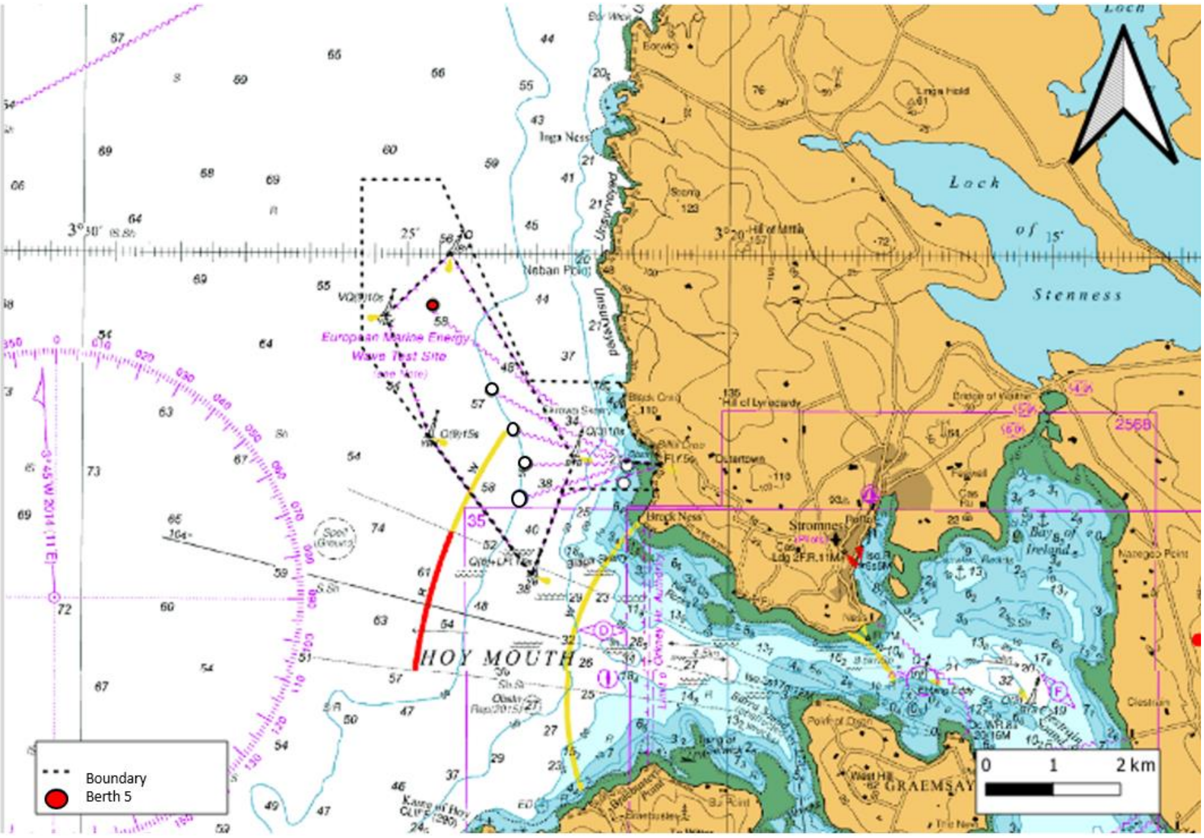

Figure 1 | OE35 Deployment location at Berth 5 (red dot), Billia Croo wave test site, west of Orkney (58° 59.522'N 3°24.563'W) (source: EMEC).

2.1.1 Routine site maintenance

Maintenance of each of the Waverider buoys is conducted every six months as part of EMEC's routine site maintenance. During offshore operations the Waverider is mechanically lifted onto a vessel, and maintenance procedures are carried out, including checking the moorings and removing biofouling, before re-deploying into the sea.

2.2 OE35 device

The OE35 device is a 1 MegaWatt utility-scale floating oscillating water column (OWC) with a large, submerged, chamber open to the sea and filled with water. The plenum chamber is situated to the bow and the opening of the water tunnels is situated at the aft end of the device (Figure 2). The water column connects to a trapped air volume in the plenum chamber through the submerged horizontal tunnels. The water pressure fluctuations due to the wave motion combined with the body motion of the device causes varying water pressure in the air plenum. This plenum is connected via ducting to an air turbine and the air is forced out of the plenum and drawn in during the wave cycle. This flow of air spins the turbine to generate electricity. The turbine is of a self-rectifying type that spins in the same direction on both the outflow and inflow stroke.

At 35m long by 19m wide, and with 10m draft, the OWC system is supported by a large buoyancy chamber. The principle of the WEC operation is shown in Figure 3. The self-rectifying air turbine to be used in this demonstration is a Wells Turbine which has only one moving part not in contact with the sea, which is the rotor connected to the electrical generator. The above-surface placement of the turbine is advantageous in reducing damage from biofouling and corrosion.

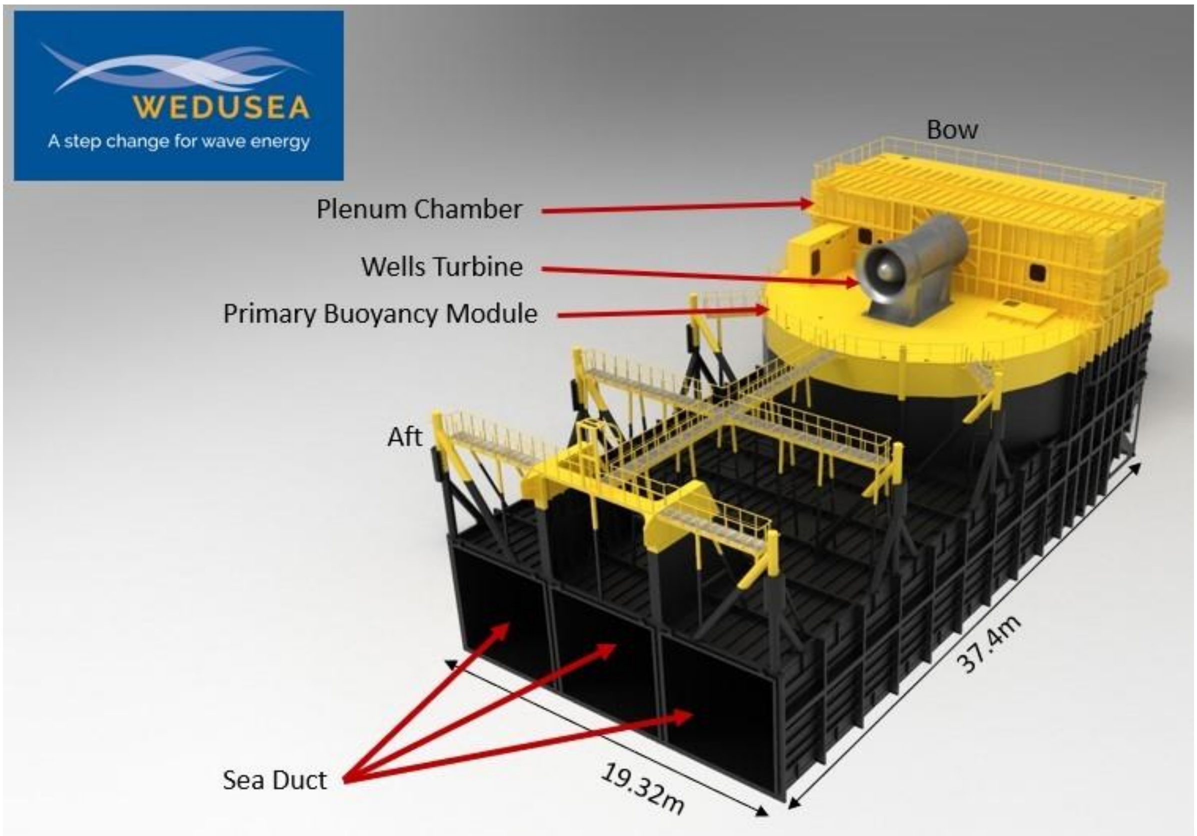

Figure 2 | Graphic of the OE35 1 MW OWC design, showing the separation of surface (yellow) and underwater (black) structures (source: Ocean Energy).

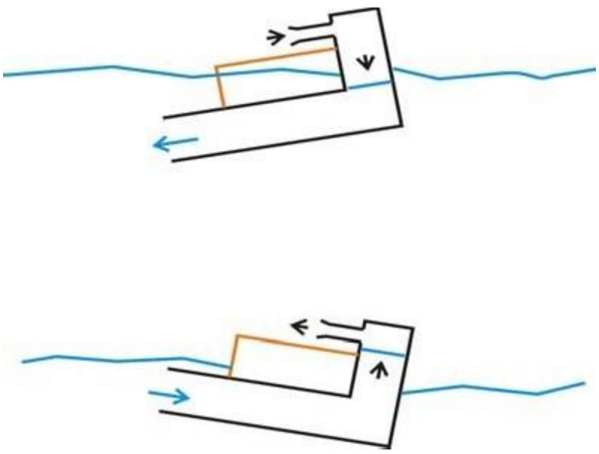

Figure 3 | Operating principle of the OE35 device.

3 Environmental impacts and monitoring

The wave energy sector is at the pre-commercial stage of development, whereby deployments generally consist of single devices or small arrays. Key evidence gaps and uncertainty about the interaction of WECs with marine species and habitats can therefore lead to a precautionary regulatory approach to consenting. Monitoring of WECs can provide developers, EMEC and the wider industry with information regarding individual device deployments and prioritisation of key environmental impacts, particularly as the industry scales up to commercial arrays. However, monitoring in high-energy, dynamic environments typical of WEC deployments presents a significant technical challenge regarding data collection and reliably capturing rare wildlife-device interaction events. Research efforts continue to progress environmental monitoring technologies and protocols that are specifically suited for application in such conditions.

To inform the environmental monitoring campaigns proposed in this plan, current evidence and industry consensus were consulted to identify key potential environmental impacts that are likely to be associated with the OE35 device demonstration, and include the following:

- European Marine Board Future Science Brief 9: European offshore renewable energy – Towards a Sustainable Future (Soukissian et al., 2023)
- OES-Environmental 2020 State of the Science Report (Copping and Hemery, 2020)
- Offshore Renewables Joint Industry Programme for Ocean Energy (ORJIP): Wave and Tidal Stream Critical Evidence Needs (ORJIP, 2020)
- The Strategic Environmental Assessment of Wave energy technologies (SEA Wave) project[1]

Literature was reviewed to identify best available practices and emerging monitoring technologies that will be utilised under the WEDUSEA project. Each plan will be supported by EMEC's own technical and operational experience in conducting offshore surveys. Table 1 presents WP7 tasks against key potential impacts that are likely to be associated with the OE35 device and proposed monitoring activities. Detailed descriptions of each planned activity are provided in the following Sections 4 to 8.

Table 1 | WP7 tasks, potential environmental impacts, and corresponding proposed monitoring activities.

WP7 Task	Key potential impacts	Monitoring activities
Biological receptors		
7.1 Underwater and airborne sound signatures and impact	• Potential for underwater noise generated by the OE35 device to be detectable by sensitive marine receptors (i.e., cetaceans) • Potential for airborne noise generated by the surface wells turbine to disturb nearby avian receptors (i.e., seabirds)	• Seabed-mounted Passive Acoustic Monitoring (PAM) frames for: - Device acoustic characterisation - Sounds of biological origin • Device-mounted microphone package for airborne acoustic measurements
7.2 Biophysical assessment: wave dynamics, fish aggregation and predator-prey interactions	Potential for the OE35 device to act as a fish aggregating device (FAD) for prey species	Active acoustic assessment of fish presence coupled with oceanographic measurements
7.4 Device interactions with seabirds	• Potential for the OE35 device to provide a resting platform for seabirds	• Optical camera surveillance around surface elements of the OE35 device

[1] Available at: https://www.emec.org.uk/projects/ocean-energy-projects/environmental-monitoring/sea-wave-strategic-environmental-assessment-of-wave-energy-technologies/

WP7 Task	Key potential impacts	Monitoring activities
	• Potential for local displacement of essential activities by seabirds	• Drone-based video monitoring of seabird activity in vicinity of the OE35 device
Physical receptors		
7.3 Impact of energy extraction on regional dynamics	Potential for wider or secondary effects on hydrodynamics and sediment dynamics due to removal or alteration of wave energy flow	Numerical modelling of energy extraction effects around a single device and hypothetical array
Monitoring system performance evaluation		
7.5 Data integration and analysis	N/A	Review and analysis of lessons learnt and system development

4 Acoustic monitoring plan

4.1 Introduction

Anthropogenic underwater noise is addressed in international and national legislation (e.g., Marine Strategy Framework Directive and Habitats Directive in the EU), where regulatory protections afforded to marine animals, particularly marine mammals, require that measures be taken to minimise any ecological impacts arising from emissions of anthropogenic underwater noise (Polagye and Bassett, 2020). Acoustic emissions of marine renewable energy converters (MRECs) are therefore of regulatory concern and are often required as part of environmental assessments carried out in project consenting processes. Underwater noise generated by operational MRECs may negatively affect marine mammals that rely on sound for biological functions, including communication, social interaction, orientation, foraging, and evasion (Southall et al., 2019). While evidence suggests that underwater noise emitted by operational devices is unlikely to cause acoustic injury to marine animals, some studies suggest a possibility of behavioural responses (Polagye and Bassett, 2020).

Noise emissions generated by operational MRECs are, however, not well understood. Devices will each have a unique acoustic signature reflecting the sum of their moving parts (including mooring chains) and the mechanics behind their movement in the marine environment. The inclusion of component parts, such as hydraulics, pressurised fluids, turbines or generators, and other electrical equipment is likely to increase noise emissions from devices (Patricio et al., 2009). Few MRECs feature mechanical components on the surface which are capable of generating airborne noise, and therefore there is insufficient acoustic data to validate their potential for human and animal disturbance at range.

Small hydrophone arrays have previously been used for the detection and localisation of echolocating cetaceans (Macaulay et al., 2017; Gillespie et al., 2020). Noise source localisation in this manner has not yet been used to discriminate between ambient noise (i.e., all background noise in the ocean, excluding the sound source of interest) and noise generated by the MREC of interest, for which there is no internationally agreed method and remains a critical knowledge gap in underwater acoustic monitoring around MRECs (Polagye and Bassett, 2020). Trialling the use of hydrophone arrays for localising noise sources, compared to the known location of a MREC device, may assist with identifying acoustic signals from the MREC itself.

4.2 Objective

This acoustic monitoring plan will inform the measurement campaigns to be conducted under Task 7.1. Underwater and airborne sound signatures and impact. The main objective is to collect underwater and airborne acoustic data during different operation modes of the OE Buoy and at a range of distances from the noise source, in order to contribute knowledge of noise characteristics associated with the floating OWC technology design and allow estimation of propagation loss (i.e., how sound levels decrease as a sound wave travels away from the source). The secondary objective is to configure a hydrophone array to enable sound localisation, to investigate both WEC-generated noise compared to its known position, and the potential presence and use of the area by vocalising marine mammals.

4.3 Previous work

4.3.1 Underwater acoustic survey programmes

In 2010 EMEC received research funding from the Scottish Government to investigate the acoustic output from wave energy devices operating in a high energy wave climate. The project involved assessment of available techniques and development of a data collection, processing, and analysis methodology suited to EMEC's Billia Croo wave test site. This methodology was then used in the study to produce an acoustic baseline description of the test site (Lepper et al., 2012).

Characterisation of the ambient soundscape at the Billia Croo test site was achieved during the summers of 2019, 2020 and 2021 under the SEA Wave project. Due to resource constraints monitoring was limited to short annual summer recording periods (University of Exeter, 2021b), however, acoustic datasets collected, analysed and shared with EMEC by the University of Exeter provides a useful contextual basis to inform the planned WEDUSEA project scope of acoustic monitoring.

4.3.2 Distribution of sensitive receptors

All species of cetacean that are present in British waters are designated as European Protected Species (EPS) under the Habitats Regulations 1994, and therefore are of regulatory priority with respect to project consenting. While there are no known resident populations of cetaceans in the wider Orkney area, data collected during the EMEC Wildlife Observations Programme for Billia Croo between 2009-2015[2] showed harbour porpoise *Phocoena phocoena* were the most abundant species to occur in the Billia Croo area (39% of cetacean observations), followed by Risso's dolphin *Grampus griseus* (16%) and Atlantic white-sided dolphin *Lagenorhynchus acutus* (12%), with several other species infrequently visiting the area. However, given their wide spatial distribution and range in wider Scottish and UK waters, Billia Croo is not considered a hotspot for cetacean activity.

4.4 Underwater acoustic monitoring

4.4.1 Approach to data collection

Measuring source levels from operational WECs and characterisation of the background ambient soundscape will help determine the likely received noise levels that marine animal receptors will experience within the test area. Data collection and analysis will be conducted following guidance provided in the International Electrotechnical Commission (IEC) Technical Specification 62600-40:2019 *Acoustic characterization of marine energy converters* ("IEC-40"). This IEC specification aims to standardise the methods used to characterise sound from wave, tidal and ocean thermal energy

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[2] Available at: https://marine.gov.scot/information/emec-billia-croo-wildlife-observation-programme

converters, and any lessons learnt from applying the prescribed methods can provide useful feedback for their continued development and improvement.

The survey is planned to be performed at three fixed locations around the OE35 device (Figure 4), one aligned with the dominant wave direction and the second across the wave direction. It is anticipated that these two locations will be at minimum 100m from the centre of the OE35 device position, as per the IEC-40. However, this will remain flexible in the event that any operational constraint is identified during detailed deployment planning.

Attribution of sound to a MREC is based on a comparison of sound recorded at a specified range from the device to a reference level, which will be represented by the third location. Per the IEC-40 specifications, the reference level is defined as a synchronous observation at an acoustically similar location. This location should be no greater than 2km from the MEC, have a water depth within 10% of the MREC deployment site, and have no material proximity difference to sources of ambient noise that are observable at the MREC site.

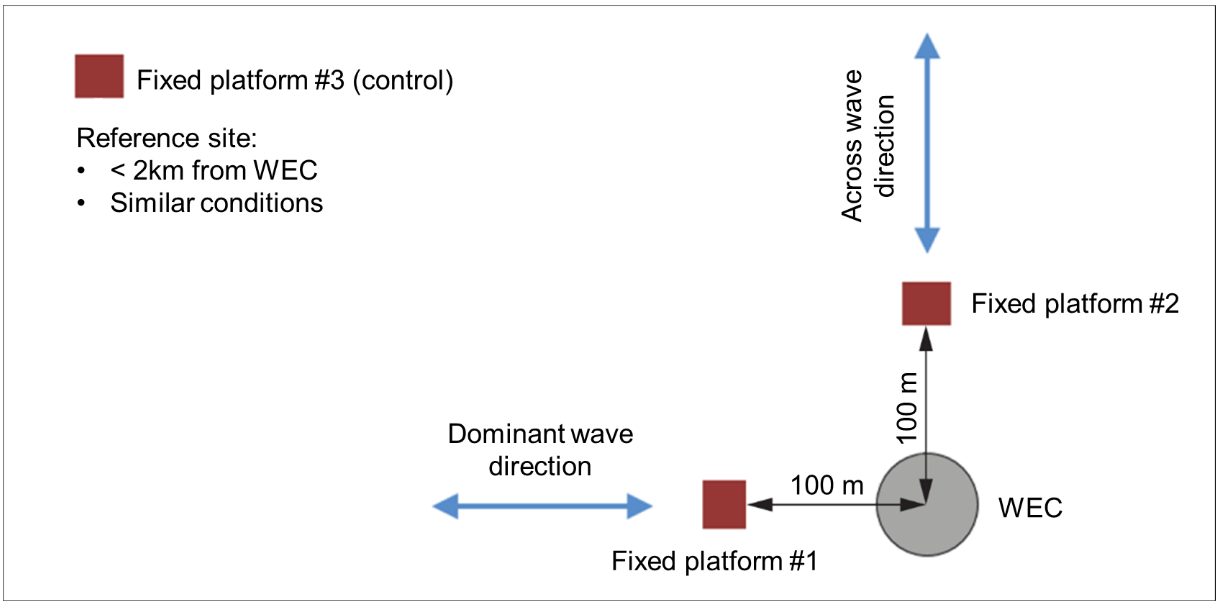

Figure 4 | Proposed layout for fixed acoustic measurement platforms relative to the WEC position (image adapted from IEC TS 62600-40).

At each location, a fixed measurement platform will house a three-hydrophone array and battery-powered multichannel acoustic recorder. The use of three hydrophones reduces the left-right ambiguity in source estimation and will enable the determination of a two-dimensional location (depth and range; Macaulay et al., 2017). Hydrophones will be positioned vertically in a triangle formation and positioned 1m apart on the instrument frame. Due to often severe weather and wave conditions that are experienced at the Billia Croo test site (with an average significant wave height of 2-3m), the fixed measurement platforms will be seabed-mounted and follow a robust design and deployment methodology similar to that of an Acoustic Doppler Current Profiler (ADCP) frame typically deployed by EMEC for resource characterisation in energetic environments (Figure 5).

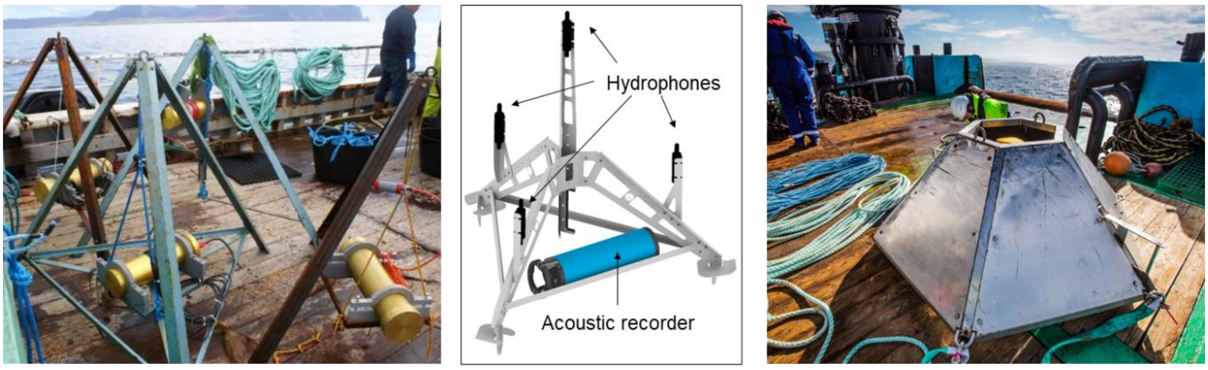

Figure 5 | Acoustic frame development. ***Left:*** **early steel tripods supporting one hydrophone system, used for baseline acoustic characterisation at Billia Croo (from Lepper et al., 2012).** ***Middle:*** **example of hydrophone array supported on an autonomous subsea tripod from Ocean Sonics[3].** ***Right:*** **example of ADCP frame (source: EMEC).**

During this period of deployment, the GPS position of each station will be recorded, as well as additional contextual information to support analysis of the acoustic data. Records from the Waverider buoy and corresponding OE35 device operational status should be obtained for comparison of sound levels with respect to sea state, per the IEC-40 recommendations. A log of weather conditions will help assess the potential influence of wind and precipitation on recordings, as well as a log of other anthropogenic noise sources (predominantly vessel activity) in the area during the time of deployment to identify noteworthy sounds or noise events during processing (Section 4.6).

A key limitation of fixed measurement platforms is their susceptibility to flow noise, which is a type of low-frequency noise contamination (less than 1 kilohertz) caused by water flow advected over the pressure-sensitive element of a hydrophone and has the potential to mask propagating MREC noise below a certain frequency. While seabed platforms in wave environments are generally least affected by flow noise due to the decay of wave orbital motion with depth, available recommendations from the IEC-40 specifications will be considered for potential flow shield materials to protect the pressure-sensitive element of each hydrophone. Furthermore, the acoustic frame will be developed to minimise mechanical self-noise as far as possible, including avoiding the potential for metal-metal contact (such as with the use of shackles), minimising the use of chains in supports, and avoiding placing the hydrophones less than 1m from the seabed.

4.4.2 Equipment

Measurements will be made using pre-amplified omnidirectional hydrophones that are suited for wideband frequencies. The IEC-40 identifies 10Hz – 100kHz as the frequency band selected to cover most of the frequencies that may be audible to marine wildlife, however this campaign will additionally seek to measure sound at higher frequencies of up to 150 kHz to detect the potential presence of vocalising marine mammals. Hydrophones will be connected to an acoustic recorder which will operate autonomously and collect acoustic data on a duty cycle (i.e., intermittent operation rather than continuous recording). Sampling will be configured to enable the desired deployment longevity. Specifications of two options for hydrophone-acoustic recorder systems under consideration are presented in Table 2.

[3] Available at: https://oceansonics.com/products/subsea-tripod/

Table 2 | Comparison of hydrophone-multichannel acoustic recorder system specifications.

Specification	Option 1	Option 2
Bandwidth	10 Hz – 150 kHz	5 Hz – 170 kHz
Sensitivity	-165 dB or -185 dB re 1 µPa	-178 dB re 1 µPa
Sampling rates	24, 48, 96, 192, 384 kHz	39, 78, 156, 312, 625 kHz
Analog-digital converter (ADC) No. bits	16	16, 24, or 32 bits acquisition
Memory	4 TB at full capacity (2 TB SSD, 2 TB SD card)	128 GB or 256 GB SD Card, with optional 1 or 2 TB HDD or 600GB SSD
Recording and duty cycling	Configurable on software	Configurable on software
Communications	Ethernet High Speed USB for download	Ethernet
Power	72 Alkaline D Cells (user replaceable) Average Power Consumption: 300mW – 3W depending on use	6 D cell batteries with option for extended room for up to 18, 54, or rechargeable batteries Power consumption: 0.6 – 2.5W while operating
Acoustic file format	Multi-channel .wav file	Multi-channel .wav file

4.5 Airborne acoustics

Airborne acoustic data will be gathered using two methods to capture the spatial and temporal variation in noise generated by the surface turbine.

A vessel-based survey campaign to obtain spatial measurements of airborne noise will be planned using a sound level meter system and calibrator for *in-situ* calibration checks. Based on a planned minimum of three survey days, measurements will be taken of ambient noise and device-radiated noise at pre-defined distances from the OE35 device. In order to minimise noise contamination associated with the vessel, mitigation options will be considered in advance with the marine contractor.

Extremes of weather and sea state in Orkney during peak winter months, can greatly limit accessibility for marine operations and survey activities at the Billia Croo site. Therefore, an environmental noise monitoring system will be installed onto the device and contained within a weather-protective enclosure to facilitate long-term unattended monitoring. Use of this system will aim to address the data gap associated with survey accessibility over winter months, by recording over periods when the device may be operating at higher generation capacities respective to sea state. Furthermore, this data collected by this instrumentation will be integrated into the OE35 device's Data Acquisition System (DAQ) under development by partners UCC, allowing for remote monitoring and download for assessment.

4.6 Data processing and software

Acoustic signal data will be processed using MATLAB (*Mathworks*) and PAMGuide acoustic analysis software (Merchant et al., 2015). Spectrograms will be generated for visual inspection of noteworthy sounds or noise events, including potential sources of contamination. The IEC-40 specifications will be used as a guide in deriving metrics to characterise sound outputs of the OE35 device:

- Broadband sound pressure level (SPL): most suitable for continuous sounds and expresses sound amplitude within a given time window and frequency range as a single decibel level (expressed as decibels referenced to a pressure of 1 microPascal (dB re 1 µPa)).
- Power spectral density (PSD): shows the energy distribution into frequency components that compose the acoustics signal, allowing the frequency at which the device is operating to be identified; and therefore, to assess how the sound will be perceived by the different species.
- Third-octave band levels (TOLs): which show the energy distribution at specific frequency bands, whose bandwidth is one third of an octave (where an octave represents a doubling in frequency). This approach simplifies the data and is appropriate for most considerations of environmental impact (Robinson et al., 2014). Narrowband frequency analysis may be further pursued if any tonal sound (i.e., occurring at a single frequency) is detected.

Available acoustic data will be used in assessments of propagation loss to estimate the acoustic impact range for the OE35 device. The detection of sounds of biological origin such as echolocating cetaceans will be performed via post-hoc screening of data in the PAM software PAMGUARD (maintained by the Sea Mammal Research Unit).

4.7 Reporting and deliverables

The outputs from underwater and airborne acoustic monitoring campaigns will be presented in the D7.1 Airborne and Underwater OE Technology Signature Report. Operational and technical lessons learnt from underwater acoustic monitoring conducted in alignment with IEC TS 62600-40:2019 will be included in the D8.5 Report on the contribution to International Standards.

5 Biophysical interactions monitoring plan

5.1 Introduction

The introduction of offshore artificial substrates may result in the attraction of fish to the structure, meaning that floating WECs in particular may act as fish aggregating devices (FADs) over time. This may subsequently influence marine mammal and seabird distribution as FAD effects could offer enhanced foraging efficiency for some predator species, altering predator-prey dynamics.

Active acoustic technologies have been identified as a valuable approach for monitoring the occurrence of marine animal targets in the water column, where the performance of underwater cameras is typically limited by poor visibility. Active acoustics record the echo of an acoustic pulse (or ‘ping’) emitted into the water column from a transducer and reflected back (backscatter) from the organism (Simmonds and MacLennan, 2008), to detect and accurately localise their position in the water column. Types of active acoustic equipment include single beam and split beam echosounders, multibeam sonar and acoustic cameras.

Hydroacoustic sampling further provides a proxy measure for density and distribution of marine animals in form of acoustic backscattering (Scherelis et al., 2020). There is growing interest in the use of an ADCP in combination with other survey methodologies, as it has the potential to add value in understanding a species’ behavioural ecology (Lieber et al., 2018). Recent developments in ADCP technology include models fitted with both oceanographic sensing and scientific echosounder capabilities, which have been demonstrated for use in assessing fish presence and biomass (Velasco et al., 2021). From a MREC resource and environmental assessment perspective, the use of a single instrument such as an ADCP with synchronous functionalities may be advantageous for easier use by the operator, as well as reduced cost and complexity.

5.2 Objective

The biophysical interactions monitoring plan will inform the measurement campaigns to be implemented within Task 7.2 Biophysical assessment: wave dynamics, fish aggregation and predator-prey interactions. The main objective is to trial the use of a state-of-the-art ADCP fitted with echosounder capabilities that will allow concurrent data collection on acoustic backscatter and water column current profiling. This data will inform potential fish presence and biomass estimation in the vicinity of the OE35 device and assist the investigation of relationships to turbulence in the water column. Furthermore, this work will integrate with seabird observations under Task 7.4 (Section 6) to contribute preliminary understanding of predator-prey interactions in the presence of a large-scale floating WEC device.

5.3 Previous work

As part of the SEA Wave project, the potential for WECs to alter and/or redistribute fish abundance and biomass through attraction and aggregation was investigated by the University of Exeter. Mobile fisheries biomass acoustic surveys were performed at Billia Croo and a reference site 2.5km to the north, over three consecutive days in the summer of 2019, 2020, and 2021. The surveys achieved a broad scale understanding of the distribution and annual variability of fish biomass throughout the water column at Billia Croo. However, due to the broad scale nature of the surveys and lack of close proximity to the WEC device under investigation, it was recommended that further annual monitoring should be conducted to validate these preliminary results. Further recommendations were made to consider seasonal surveys to investigate the presence of some pelagic fish species due to migration and/or spawning events which could influence aggregation effects (University of Exeter, 2021a).

5.4 Equipment

Monitoring will be conducted with a Nortek Signature 500 ADCP configured with a concurrent current profiling and scientific echosounder sampling regime. Specifications of the Signature 500 are listed in Table 3.

Table 3 | Specifications of the Nortek Signature 500.

Signature 500 specification	
Water velocity measurements	
Range	60 m (burst mode); 70 m (average mode)
Cell size	0.5 – 4 m
Max. number of cells	256 (burst) / 200 (average)
Velocity range (along beam)	User selectable 2.5 or 5.0 m/s
Min. accuracy	0.3% of measured value ± 0.3 cm/s
Velocity precision	Broadband processing
Velocity resolution	0.1 cm/s
Max. sampling rate	8 Hz
Echosounder specification	
Number of echograms	Up to 3
Number of bins	11,000
Resolution	6 mm – 1.0 m
Range	70 m
Transmit pulse length	32 µs – 1 ms
Transmit pulse frequency	500 kHz
Transmit pulse types	Monochromatic; Pulse compressed (25%BW)
Resolution / Dynamic range	0.01 dB / 70 dB

5.5 Approach to data collection and calibration

The ADCP-echosounder equipment will be deployed on the seabed in an upward-facing direction and housed on a robust stainless steel instrumentation frame (Figure 6). Two ADCP-echosounder deployments are planned during the period of OE35 device demonstration. Detailed planning of operational schedules, logistics and placement will be conducted in line with established EMEC procedures for traditional ADCP deployments, typically conducted as part of resource characterisation and Power Performance Assessments (PPA) across its test sites.

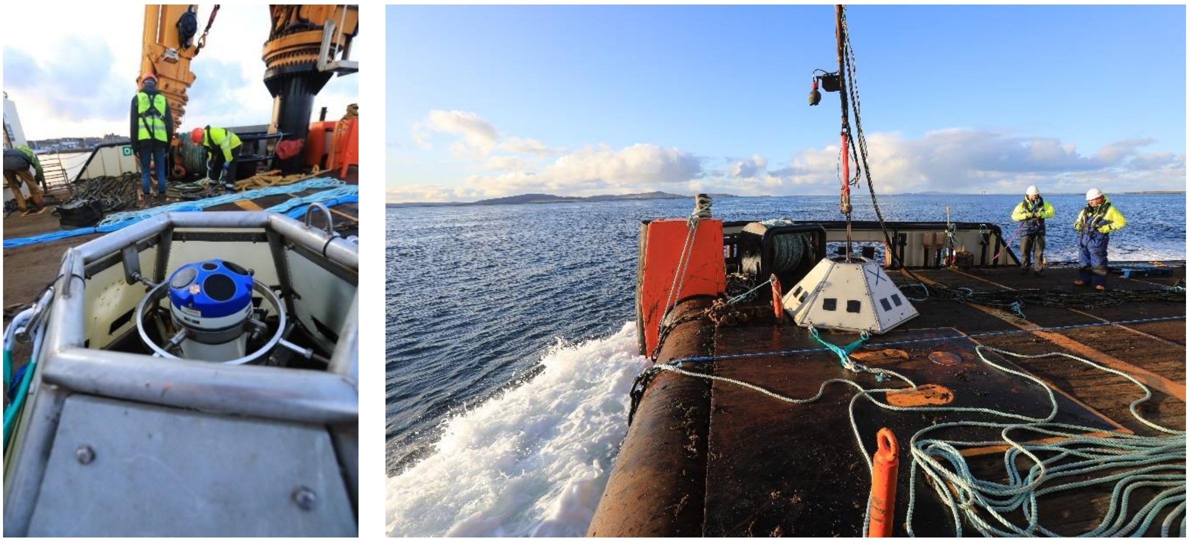

Figure 6 | Example of ADCP frame for seabed mounting (left) and deployment operations (right) (source: EMEC).

The incorporation of echosounder functionality into an ADCP can significantly increase the power and memory requirements of the overall equipment. For example, during a 136-day deployment of a Signature 100 ADCP at 370m depth, Velasco et al. (2021) reported that of the total data generation (62 gigabytes) and power supply (1800 watt-hours) requirements, the ADCP respectively accounted for 0.8% and 20% of the total, compared to 99.2% and 80% used by the echosounder. In respect of this, the sampling strategy for the ADCP-echosounder deployments planned within the WEDUSEA project will be configured as appropriate to optimise the deployment duration without exceeding memory and power capacity. Using Nortek's proprietary Signature Deployment software (v4.6.15) to test initial configurations, the ADCP-echosound will be planned to be deployed to collect data for a duration of up to 60 days, with an estimated maximum length of around 100 days to allow for contingency in recovery operations.

Echosounder calibration is a crucial requirement in quantitative marine biomass surveys. In situ calibration of echosounder instruments deployed onto the seabed in an upward-facing configuration are required to reduce bias in estimates of biomass and improve species identification (Haris, 2017). In-situ calibration will be performed using the sphere method as described by Demer et al. (2015), in which a solid sphere with known target strength (e.g., 23 mm copper calibration sphere) will be suspended in the water column with sufficient ballast to stabilise the position of the sphere, assisted by a surface vessel. Two vessel trips are planned for the echosounder calibrations (i.e., one excursion per ADCP-echosounder deployment).

5.6 Data processing and software

Processing of oceanographic data will be conducted using a combination of EMEC's proprietary metocean data processing software, Integrated Metocean Processing and Quality Control tool (IMPAQCT) and MATLAB for post-processing and flexible data visualisation. IMPAQCT provides a fully traceable and auditable quality control and processing of wave and tidal resource data surveys. Hydroacoustic data from the echosounder will be processed using MATLAB and ESP3 software for echosounder data processing (Ladroit et al., 2020). To enable analysis of fish presence and distribution, post-processing will include the removal of acoustic backscatter recorded from physical interfaces, including from entrained air in the water column and at the sea-air interface (Lowe et al., 2022). Processed data will be examined for potential evidence of fish aggregation effects.

5.7 Reporting and deliverables

The outputs of ADCP-echosounder measurement campaigns will be included in D7.2 OE Technology Ecological Impact Report: Year 1 and D7.3 OE Technology Ecological Impact Report: Year 2. In addition, analyses on system efficiency, lessons learnt and recommendations for future deployments will feed into D7.4 Environmental monitoring system design and performance analysis, with particular focus on evaluating cost efficient efforts to assess environmental impact of WECs.

6 Seabird interactions monitoring plan

6.1 Introduction

High energy, nutrient rich seas around Orkney support a rich and abundant marine life including high numbers of marine birds year-round. Orkney waters are part of a wider marine area extending around the coast of Scotland that has international importance for its populations of several seabird species. This importance is formally recognised by numerous sites that have been designated under international legislation to protect breeding sites, foraging grounds and wintering areas. Throughout the year the Billia Croo area is used primarily for foraging and resting activities by the following bird groups: divers, ducks, petrels, gulls, auks, and skuas. In an Orkney-wide context, the Billia Croo site generally has low or very low importance for these groups. Specific exceptions include European shag (*Phalacrocorax aristotelis*), black-legged kittiwake (*Rissa tridactyla*) and northern fulmar (*Fulmarus glacialis*), all of which are sometimes present in relatively large numbers and therefore the site is considered to be of low-moderate importance to these species. Kittiwakes and fulmars are among the key species of the Hoy Special Protection Area (SPA), situated approximately 5.65km south of Billia Croo berth 5 at its nearest boundary. European shag is among the qualifying species of the Scapa Flow Special Protection Area (SPA), situated approximately 6.15km southeast of berth 5 at its nearest boundary.

While collision risk to marine mammals and seabirds is of priority regulatory concern specifically within the tidal stream industry, the general consensus is that this is less of a priority risk for wave energy (Hutchison et al., 2022). There is the potential for seabirds to be disturbed by operational noise from the above-water turbine on the OE35 device. Continued disturbance and active avoidance of the area around MRECs may lead to species displacement, in which an individual or population changes its home range or movement patterns as a result of change in their environment that prevents access to critical foraging, mating, rearing or resting habitats. While the risk of displacement is regarded very low with respect to a single device demonstration, it remains uncertain whether this will occur over greater spatial and temporal scales as demonstrations progress to large-scale arrays (OES-Environmental, 2022).

Surface-floating WECs have the potential to provide some seabirds with a roosting platform under calm sea conditions (Furness et al., 2012). Anecdotal evidence from floating MREC demonstrations at EMEC's sites have further indicated seabird roosting activity on exposed surfaces. As shown in Figure 2, the surface-piercing elements of the OE35 device offer expansive flat surfaces and railings which may provide opportunities for seabird use. Furthermore, potential aggregations of fish around WECs could further attract foraging seabirds by providing locally high densities of prey (Furness et al., 2012).

6.2 Objective

This seabird interactions monitoring plan will inform the measurement campaigns to be implemented within Task 7.4. Device interactions with seabirds. The main objective is to collect drone footage directly above and in the vicinity of the OE35 device, to assess the presence and spatial pattern of use by seabirds and provide preliminary context on species' behavioural response to the large-scale OE35 device. These drone footage observations will be supplemented with sampling video footage from onboard camera surveillance for a closer view of any potential roosting activity.

6.3 Previous work

EMEC's Wildlife Observations Programme consisted of extensive shore-based observations of presence, distribution and behavioural data relating to seabirds and marine mammals across its test sites. In-depth analysis of this observational data was conducted to provide an insight into the potential displacement and/or redistribution of wildlife within the study regions that can be associated with marine energy converter activity.

Observations of surface-visible species (such as basking shark, European otter, seabirds, and marine mammals including seals and harbour porpoise) around devices were relatively consistent across EMEC's test site study areas. While temporary displacement of animals was noted during the installation of MRE devices and likely associated with vessel activity, normal sightings resumed after the work phase was over and devices were operational (Long, 2017).

Under the Blue Growth and Innovation Fast Tracked (BlueGIFT) project, EMEC appointed contractors in 2021 to trial a five-day aerial video survey of marine wildlife across its Fall of Warness tidal energy test site. The aim of the survey was to develop an appropriate methodology to characterise marine species presence and density, which could be used to validate the Wildlife Observations Programme. The survey was a valuable exercise in finding the most suitable approaches for clear observation of species targets while understanding principal constraints that should be factored into planning for future campaigns.

6.4 Digital aerial surveys

Traditionally manned aircraft was used for aerial surveys of species distribution, however, growth in the application of unmanned aerial vehicles (UAVs or drones) and associated aerial imaging technology has shown to enable the collection of highly accurate, detailed and verifiable data about the survey area (Gonzalez et al., 2016). Small drones (less than 2kg) are particularly useful for their potential in conducting intensive, repeatable wildlife surveys due to their affordability and relative ease of operation (Cleguer et al., 2021). Remote monitoring of marine wildlife is becoming increasingly explored due to advancements in imaging technology and flight endurance, therefore EMEC will deploy a drone for overhead observational monitoring of seabird use and activity on and around the OE35 device, to complement the device's onboard cameras.

6.4.1 Approach to data collection

Drone survey campaigns will be planned in conjunction with seasonal periods for qualifying species of both Hoy SPA and Scapa Flow SPA, in which the breeding season broadly spans between March to early September, and non-breeding season occurring from October to February (NatureScot, 2020).

A key limitation for operating drones is their flight time due to battery life, which depending on the model may vary between 30 – 45 minutes in pristine weather conditions and may be as low as 20 minutes in harsher conditions. Due to the distance of the OE35 device from shore, vessel-based survey campaigns are proposed with a number of pre-determined fixed-point observations viewing directly down at the sea surface, positioned above and around the OE35 device. A fixed-point survey will allow rotational use of battery packs between the drone and battery chargers, extending operations and limiting interruptions to switch out batteries between flight missions.

The longevity of survey campaigns will vary depending on the monitoring objective and planned area of coverage by the drone system. It is envisaged that a single vessel-based campaign may extend up to five survey days (returning to shore at the end of each day). However, contingency measures for mobilisation will be crucial for the survey campaign, as unsuitable weather forms a major constraint for drone flights. Wind speeds must not exceed more than 21-24 meters per second (m/s) and there should be very little to no precipitation, as once water droplets sit on the camera lens, this will obscure image clarity and require the drone to be retrieved. In addition, drone operators must be aware if any potential temporary aviation restrictions have been set in place by controlling authorities.

During detailed flight planning, literature will be consulted on previous survey methods and guidance will be followed where available to investigate the most appropriate flight altitude that balances visibility of seabird targets with minimising potential incidental disturbance caused by the presence of the drone (for example, previous studies have flown an average altitude of 70 – 120m; Slinsgby et al, 2022; Lieber et al., 2019). Flights may incorporate an initial period of hovering to habituate seabirds to the presence of the overhead drone (Brisson-Curadeau et al., 2017).

All flight personnel and operations will respectively meet the requirements set by the UK Civil Aviation Authority (CAA), and all survey operations will be planned in line with EMEC's standard methodology and risk assessment process.

6.4.2 Equipment

The frequency and longevity of a marine wildlife monitoring survey using aerial methods should be taken into account when considering the type of drone equipment. Recent studies have investigated seabird association with hydrodynamic features in tidally energetic sites (Slingsby et al., 2022) and around tidal energy installations (Lieber et al., 2019; Lieber 2022), which used commercial off-the shelf drone models. These offer the advantage for being more lightweight affordable, offering high-quality imagery and easier to operate. Of commercially available models, two options under consideration are provided in Table 4.

Table 4 | Comparison of options under consideration for drone systems.

Specification	Option 1	Option 2
Takeoff weight	895g	1375g
Max takeoff altitude	6000m	6000m
Max. flight time	46 minutes (in controlled windless conditions)	30 minutes
Max. hovering time	40 minutes (in controlled windless conditions)	28 minutes

Specification	Option 1	Option 2
Max. flight distance	30km	14km
Storage	8 GB internal; range of compatible SD cards (64, 128, 256, 512 GB capacity)	microSD with 128 GB max. capacity
Battery capacity	5000 mAh	5870 mAh
Voltage	15.4 V	15.2 V
Charger rated power	65 W	100 W
Camera sensor	Hasselblad camera: 4/3 CMOS Tele camera: ½" CMOS	1" CMOS
Lens	Hasselblad: FOV 84° Tele camera: FOV 15° (zoom option)	FOV 84°
Video resolution	4K/120fps	4K/60fps
Stills resolution	20 MP	20 MP
Remote controller	Yes	Yes

6.5 Onboard camera surveillance

Video camera surveillance is planned for the OE35 device for the principal purpose of remote visual observations of the deck, and which will form one of several sensor components feeding into the device onboard DAQ system (in addition to the airborne noise monitoring system, Section 4.5). In addition to the dedicated drone survey campaigns, live video feeds from the onboard cameras will be manually interrogated by human analysts for the potential presence and activity of seabirds captured in the footage.

6.5.1 Maintenance recommendations

Due to the harsh conditions the onboard cameras will be subject to whilst on site (e.g., high moisture and salt deposition), checks of the equipment are proposed to be part of scheduled maintenance operations. Activities will include lens cleaning (or replacement, if necessary), checking camera housing is well-sealed to prevent fogging due to moisture, and that all connections and entry points are re-sealed with silicone grease to create a moisture barrier.

6.6 Data processing and software

Drone video sequences will be manually reviewed and subsequently post-processed using MATLAB. Images will be assigned corresponding geographical coordinates to allow for conversion of image units (pixels to metres), in order to support analysis of seabird abundance and wider spatial distribution.

Video data from onboard cameras will be sampled for short periods and manually analysed to understand bird species presence, and use of the device. This data will be reviewed in consideration of the OE35 device operational status to understand species' avoidance or potential for habituation across different operation modes.

6.7 Reporting and deliverables

The output of seabird monitoring campaigns will be presented in D7.5 Results of seabird surveys and observations: Year one and D7.6 Results of seabird surveys and observations: Year two.

7 Energy extraction impacts and modelling

It has been proposed that large-scale extraction of energy by MRECs could lead to near- and far-field alteration to oceanic processes including changing natural flow patterns, altered sediment dynamics, and removing energy from the system. This impact applies to large-scale arrays as it is widely accepted that single installations are unlikely to significantly disrupt the oceanographic system into which they are deployed because any potential changes will be too small to measure, compared to natural variability. Numerical models are currently used to predict the influences a WEC may have on physical parameters, however, such models must consider potential cascades into environmental changes including specific species and ecosystem processes as the scale of deployments increase (Whiting and Chang, 2020). Oceanographic measurements around future commercial-scale arrays will be crucial to validate earlier numerical models.

Task 7.3 will involve a desk-based assessment of the impact of energy extraction on regional hydrodynamics and local sediment dynamics. The main objective of this work is to numerically model the extent of energy extraction effects, with simulations considering the single 1 MW utility-scale device up to a hypothetical array, to understand the spatial scale of such effects and how they may impact on ocean, coastal, and sediment dynamics.

To support the preparation for this task and inform holistic computation of sediment mobilisation and transport due to currents and waves, EMEC has provided OE with a detailed report published in 2011 on the construction, calibration, and validation of numerical hydrodynamic and wave models (including estimations of extreme wave statistics) at the Billia Croo test site. In addition, EMEC has provided up-to-date geophysical and geotechnical survey data collected at Billia Croo during summer 2022. During the project EMEC will support the development of numerical models that will be used to estimate potential effects of the OE35 device by contributing wave and tidal resource parameters acquired respectively from the on-site Waverider buoy and ADCP deployed under Task 7.2 (Section 5).

Outputs from this task will feed into deliverables reported under WP8 Data Collection, Device Performance & Monitoring, with lessons learnt captured in D7.4 Environmental monitoring system design and performance analysis.

8 Data integration and analysis

One of the biggest bottlenecks to acquiring meaningful outcomes relevant to environmental monitoring objectives is the management of significant datasets. Reliable detection of rare near-field interactions of wildlife with operational devices may require continuous data acquisition over long periods of time (on the order of months to years). The use of multiple instruments within a monitoring programme has the potential to generate significant volumes of data, termed “data mortgage”. For example, a single 5-megapixel camera with a 10Hz frame rate could accrue more than 2 terabytes of uncompressed images in a single day (Hasselman et al., 2020). Extensive data mortgages can lead to a “data-rich information-poor” situation (Wilding et al., 2017), where costly challenges associated with processing and analysis risks the reduced ability to draw meaningful conclusions from the dataset. It is recommended that a data management plan is be produced for each programme, with details spanning collection, processing, storage, transfer, dissemination, and subsequent in-house storage (Hutchison et al., 2020). However, currently there are insufficient resources or guidance to support the sector in adopting best practices.

Under Task 7.5, an analysis guideline for data generated from environmental monitoring activities across WP7 will be developed, considering options for powering the equipment, data storage and transfer. Throughout each campaign lessons learnt will be gathered on instrumentation performance and fail-safe mechanisms against hardware failure, with the aim of improving data return and future monitoring cost estimations. This work will interface with activities under WP8 relating to implementation of the DAQ system for monitoring of non-critical signals and data-intensive monitoring.

The outputs of this work will be presented in D7.4 Environmental monitoring system design and performance analysis and D7.7 Overall Environmental monitoring analysis and report, which will represent the culmination of works across the entirety of WP7.

9 Environmental Monitoring Schedule

Work Package (WP) 7 of the WEDUSEA project encompasses an environmental monitoring program that will be carried out between months 24 and 47 of the project timeline. The proposed program is designed to adapt to weather patterns and seasonal fluctuations and comprises several monitoring activities detailed in "Appendix A." These tasks include the installation of an environmental noise acoustic monitoring system on the OE buoy for continuous data collection throughout its deployment period. Additionally, a vessel-based airborne acoustics survey is planned within the initial 12 months of deployment. ADCP-echosounder frames will be deployed twice during the 24-month period, collecting data for up to 60 days each time, with a provision for extended operation up to 100 days to accommodate potential recovery operations. Furthermore, underwater acoustic frames are scheduled for deployment on the seabed for a two-month period with supplementary contingency for marine recovery efforts. Drone survey campaigns, aligned with seasonal breeding periods, will be conducted over the 24-month deployment, with each survey expected to span up to 5 days. Two vessel-based bird surveys are slated for completion within the first 12 months of deployment. Lastly, a 12-month phase will be dedicated to data integration and analysis, while resource data will be sourced from Waverider buoys at EMEC throughout the entire deployment duration.

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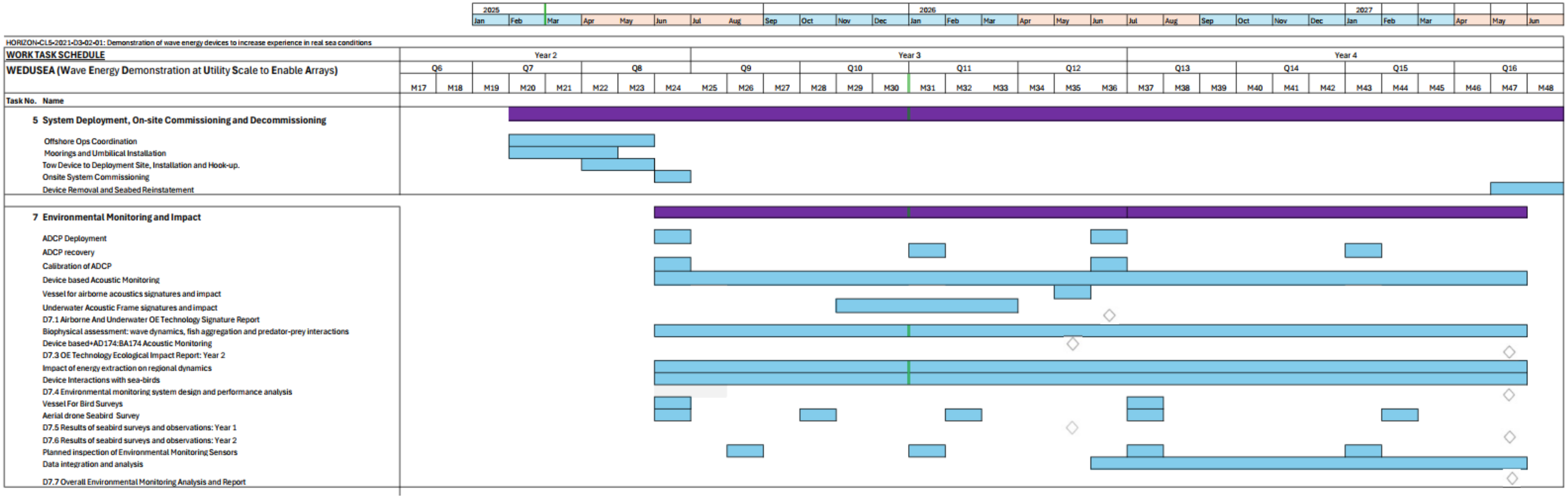
Appendix A: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HORIZON-CL5-2021-D3-02-01: Demonstration of wave energy devices to increase experience in real sea conditions
WORK TASK SCHEDULE
WEDUSEA (Wave Energy Demonstration at Utility Scale to Enable Arrays)
Year 2
Year 3
Year 4
Q6
Q7
Q8
Q9
Q10
Q11
Q12
Q13
Q14
Q15
Q16
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M48
Task No. Name
5 System Deployment, On-site Commissioning and Decommissioning
Offshore Ops Coordination
Moorings and Umbilical Installation
Tow Device to Deployment Site, Installation and Hook-up.
Onsite System Commissioning
Device Removal and Seabed Reinstatement
7 Environmental Monitoring and Impact
ADCP Deployment
ADCP recovery
Calibration of ADCP
Device based Acoustic Monitoring
Vessel for airborne acoustics signatures and impact
Underwater Acoustic Frame signatures and impact
D7.1 Airborne And Underwater OE Technology Signature Report
Biophysical assessment: wave dynamics, fish aggregation and predator-prey interactions
Device based+AD174:BA174 Acoustic Monitoring
D7.3 OE Technology Ecological Impact Report: Year 2
Impact of energy extraction on regional dynamics
Device Interactions with sea-birds
D7.4 Environmental monitoring system design and performance analysis
Vessel For Bird Surveys
Aerial drone Seabird Survey
D7.5 Results of seabird surveys and observations: Year 1
D7.6 Results of seabird surveys and observations: Year 2
Planned inspection of Environmental Monitoring Sensors
Data integration and analysis
D7.7 Overall Environmental Monitoring Analysis and Report