



SEA Wave: Strategic Environmental Assessment of Wave energy technologies

Deliverable Report D2.2

Critical analysis of environmental mitigation and monitoring strategies



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1 Introduction

This deliverable provides a critical analysis of management measures that can be used to mitigate or manage the potential environmental effects of wave and tidal energy developments.

The aim of this deliverable is to critically analyse the environmental mitigation and monitoring measures that have been used to date in completed or planned wave and tidal energy projects. This will provide the industry with knowledge of successes and lessons learnt in relation to these measures. This analysis will be used to inform the development of environmental monitoring strategies used in Work Package 3.

The objectives of this deliverable are to:

- Conduct a critical analysis of environmental mitigation and monitoring strategies for wave and tidal energy developments
- Validate this analysis with a range of stakeholders from the wave and tidal industry

This deliverable is the second piece of work within Work Package 2 and builds on the overall impact of this Work Package which will be:

- A consensus on the priority knowledge gaps and consenting issues upon which coordinated strategic data collection and research efforts should focus, ensuring improved efficiencies in the allocation of resources and distribution of effort.
- An established European Network of stakeholders and end users engaged in better understanding the potential impacts of wave developments and improving the consenting process.
- Refinement of the consenting processes for ocean energy deployments, helping to reduce costs and the time spent in achieving consent.
- Environmental monitoring strategies designed to address the key consenting risks of wave energy projects that will be implemented during the project.

This deliverable builds on previous work by OES Annex IV on the development and appraisal of environmental management measures relevant to wave and tidal energy developments. As part of this work, extensive stakeholder consultation was undertaken in order to gather a comprehensive list of management measures designed to manage the environmental effects of wave and tidal projects during construction, operation and decommissioning/removal. This list was developed into a tool designed to support the development of project specific environmental management plans, which is available on the Tethys website¹.

These management measures are intended as safeguards for marine animals and habitats until scientific uncertainty around the risk of effects of wave and tidal energy devices is reduced and such measures can be reduced or removed as appropriate.

This deliverable builds on this work, considering the advantages and disadvantages of each of the environmental management measures included in the tool to date.

¹ <https://tethys.pnnl.gov/management-measures>



2 Methodology

Environmental management measures are considered in relation to the relevant potential environmental impact. This list of potential impacts and associated management measures was informed by work carried out by the Offshore Renewables Joint Industry Programme (ORJIP) for Ocean Energy² and OES Annex IV. The relevant impacts are:

- Barrier to movement
- Change in sediment dynamics
- Changes in tidal flow, flux and turbulence
- Collision Risk
- Displacement
- Dissipation of wave energy
- Electromagnetic fields
- Entanglement
- Entrapment
- Habitat creation
- Introduction of marine non-native species
- Lighting
- Loss of seabed habitat
- Pollution
- Underwater noise
- Vessel disturbance

Key experts in the management of the impacts and potential effects of wave and tidal energy developments on the marine environment were engaged in interview style meetings to review the lists presented alongside the advantages and disadvantages of each environmental management measure.

Key stakeholders were targeted during this process, including SEA Wave project partners (test site operator, wave technology developers, consultants and academics), environmental managers within wave and tidal technology companies, statutory nature conservation bodies, regulators and consultants. The following questions formed the basis of the interviews:

- Please comment on the list of Management Measures – are there any additional measures that should be included or are there any measures that you would suggest should be changed or removed?
- Please comment specifically on the pros and cons – do you have any additional information that would be useful to include here?

² <http://www.orjip.org.uk/oceanenergy/about>



- Please add your specific experience in the use of these management measures. Did the measure work well, or not? Were there challenges in the implementation of this measure? Did you carry out monitoring to measure how well the management measure was working? Did you have to report on the implementation of the measure to regulators or stakeholders?

The results of this critical analysis is presented in Section 3.

It should be noted that some of these impacts presented are considered unlikely to occur, or should they occur, the effect to be minor. This is not an analysis of the significance of interactions or the likelihood of interactions. All possible interactions have been included here as there is a chance that they could occur and a chance that there could be a deleterious effect. This analysis is limited to a critique of the management measure that will potentially be utilised to mitigate, manage or monitor a potential interaction between marine energy devices and marine animals and habitats.

3 Critical analysis of management measures

As can be seen in the tables below, the green columns show details of the interaction and associated management measure; Interaction, Receptor, Phase of project, Environmental management measures, and Management measure category. Management measures categories are split into mitigation measure, design feature or monitoring. The blue columns on the right of each table show the advantages and disadvantages associated with each measure.

Barrier to Movement (relevant to wave and tidal)

Interaction	Receptor	Phase of project	Environmental management measures	Management measure category	Effect of management measure - advantages	Effect of management measure - challenges
Potential barrier to movement due to the physical presence of devices and associated moorings / support structures, cables and electrical equipment.	All receptors	Construction	Site selection to avoid sensitive routes/areas	Design feature	Minimises risk of development acting as a barrier to movement by avoiding migratory routes or other important sites	None identified
Potential barrier to movement due to the physical presence of devices and associated moorings / support structures, cables and electrical equipment.	All receptors	Construction	Array/ mooring configuration designed to avoid migratory routes or other important sites	Design feature	Minimises risk of development acting as a barrier to movement by avoiding migratory routes or other important sites	May be inconsistent with optimal layout of the development for exploitation of the energy source Can be a costly measure when scaling up to larger arrays
Potential barrier to movement due to the physical presence of devices and associated moorings / support structures, cables and electrical equipment.	All receptors	All phases	Adherence to vessel management plan	Mitigation	Minimises the potential interaction between animals and construction or maintenance vessels	None identified
Potential barrier to movement due to the physical presence of devices and associated moorings / support structures, cables and electrical equipment.	All receptors	All phases	Monitoring of existing developments	Monitoring	Reduces scientific uncertainty	Can be complex and costly

Table 1: Critical analysis of management measures related to the interaction of 'barrier to movement'

Changes in sediment dynamics (relevant to wave and tidal)

Interaction	Receptor	Phase of project	Environmental management measures	Management measure category	Effect of management measure - advantages	Effect of management measure - challenges
The potential wider or secondary effects (siltation changes or smothering) on protected or sensitive sub-littoral seabed due to devices and associated moorings, support structures and export cables	Benthic species	Operation & maintenance	Periodic visual monitoring through the use of divers or drop-down video, static cameras / remote sensing techniques, benthic grab surveys, geophysical survey to identify scour pits, turbidity measurements.	Monitoring	Generation of data to quantify level and spatial extent of effect.	Technical and Health and Safety risks associated with periodic monitoring operation in close vicinity of infrastructure. Power shut down potential. Subsea static monitoring options require O&M.
The potential wider or secondary effects (siltation changes or smothering) on protected or sensitive sub-littoral seabed due to devices and associated moorings, support structures and export cables	Benthic species	Operation & maintenance	Micro-siting of export cables and infrastructure to minimise the impact on sensitive habitats and species. Best practice techniques for cable installation, burial and protection.	Design feature	None identified	None identified
Reduced visibility impacting prey detection and obstruction avoidance.	Fish	All phases	Best practice methodologies to reduce resuspension of sediment during cable burial, device foundation installation, mooring installation or vessel anchor installation.	Mitigation	None identified	None identified
Disturbance resulting in smothering of fish spawning grounds	Fish	All phases	Best practice methodologies to reduce resuspension of sediment during cable burial, device foundation installation, mooring installation or vessel anchor installation.	Mitigation	None identified	None identified
The potential wider or secondary effects (siltation changes or smothering) on protected or sensitive sub-littoral seabed due to devices and associated moorings, support structures and export cables	Benthic species	All phases	Minimise the amount of structure on the seabed.	Design feature	Minimises the changes in sediment dynamics due to presence of structure on the seabed	Can present financial/ logistical/ design challenges to technology developer to alter design of device/ moorings
Reduced visibility impacting prey detection and obstruction avoidance.	Fish	All phases	Minimise the amount of structure on the seabed.	Design feature	Minimises the changes in sediment dynamics due to presence of structure on the seabed	Can present financial/ logistical/ design challenges to technology developer to alter design of device/ moorings
Disturbance resulting in smothering of fish spawning grounds	Fish	All phases	Minimise the amount of structure on the seabed.	Design feature	Minimises the changes in sediment dynamics due to presence of structure on the seabed	Can present financial/ logistical/ design challenges to technology developer to alter design of device/ moorings
The potential wider or secondary effects (siltation changes or smothering) on protected or sensitive sub-littoral seabed due to devices and associated moorings, support structures and export cables	Benthic species	Operation & maintenance	Modelling to predict the interaction between changes in sediment dynamics and animals	Monitoring	Reduces scientific uncertainty so appropriate management measures can be employed	Limited management measures available to minimise interaction despite modelling to fully predict interaction
The potential wider or secondary effects (siltation changes or smothering) on protected or sensitive sub-littoral seabed due to devices and associated	Benthic species	Operation & maintenance	Modelling to predict the interaction between changes in sediment dynamics and animals	Monitoring	Reduces scientific uncertainty so appropriate management measures can be employed	Limited management measures available to minimise interaction despite modelling to fully predict interaction

Interaction	Receptor	Phase of project	Environmental management measures	Management measure category	Effect of management measure - advantages	Effect of management measure - challenges
moorings, support structures and export cables						
Reduced visibility impacting prey detection and obstruction avoidance.	Fish	All phases	Modelling to predict the interaction between changes in sediment dynamics and animals	Monitoring	Reduces scientific uncertainty so appropriate management measures can be employed	Limited management measures available to minimise interaction despite modelling to fully predict interaction
Disturbance resulting in smothering of fish spawning grounds	Fish	All phases	Modelling to predict the interaction between changes in sediment dynamics and animals	Monitoring	Reduces scientific uncertainty so appropriate management measures can be employed	Limited management measures available to minimise interaction despite modelling to fully predict interaction

Table 2: Critical analysis of management measures related to the interaction of 'changes in sediment dynamics'

Changes in tidal flow, flux and turbulence structures (relevant to tidal only)

Interaction	Receptor	Phase of project	Environmental management measures	Management measure category	Effect of management measure - advantages	Effect of management measure - challenges
The potential wider or secondary effects on protected or sensitive sub-littoral seabed due to removal or alteration of energy flow arising from devices and moorings or support structures.	Benthic invertebrates	Operation & maintenance	Pre and post installation monitoring of sensitive benthic communities, based on diver, drop down, static visual surveys (camera) or grab sampling.	Monitoring	Reduce scientific uncertainty	Interpretation of data for statistical purposes may not have power to detect change generated by impact. May require correlation with detailed Computational Fluid Dynamics studies and physical flow measurements.
Modifications to prey distribution and abundance (to include for other receptors) resulting in changes to foraging behaviour	Marine mammals, diving birds, and fish	Operation & maintenance	Observational surveys (including remote sensing) of bird and marine mammals (prey availability linked to benthic community)	Monitoring	Reduce scientific uncertainty	Statistical power of studies can be low. Can be difficult to distinguish between natural variation and direct effects of energy removal from the system
The potential wider or secondary effects on protected or sensitive sub-littoral seabed due to removal or alteration of energy flow arising from devices and moorings or support structures.	All receptors	Operation & maintenance	Installation of ADCPs and turbulence sensors to better understand the baseline tidal flow conditions and hence the change in tidal flow due to presence of the device(s)	Monitoring	Reduce scientific uncertainty	None identified
The potential wider or secondary effects on protected or sensitive sub-littoral seabed due to removal or alteration of energy flow arising from devices and moorings or support structures.	All receptors	Operation & maintenance	Design structures to minimise effect on turbulence structure	Design feature	Minimises change in turbulence structure and hence potential interaction	Can present financial/ logistical/ design challenges to technology developer to alter design of device/ moorings
Modifications to prey distribution and abundance (to include for other receptors) resulting in changes to foraging behaviour	Marine mammals, diving birds, and fish	Operation & maintenance	Design structures to minimise effect on turbulence structure	Design feature	Minimises change in turbulence structure and hence potential interaction	Can present financial/ logistical/ design challenges to technology developer to alter design of device/ moorings
The potential wider or secondary effects on protected or sensitive sub-littoral seabed due to removal or alteration of energy flow arising from devices and moorings or support structures.	All receptors	Operation & maintenance	Modelling to predict the interaction between changes in tidal flow, flux and turbulence structure and animals	Monitoring	Reduces scientific uncertainty so appropriate management measures can be employed	Limited management measures available to minimise interaction despite modelling to fully predict interaction

Interaction	Receptor	Phase of project	Environmental management measures	Management measure category	Effect of management measure - advantages	Effect of management measure - challenges
Modifications to prey distribution and abundance (to include for other receptors) resulting in changes to foraging behaviour	Marine mammals, diving birds, and fish	Operation & maintenance	Modelling to predict the interaction between changes in tidal flow, flux and turbulence structure and animals	Monitoring	Reduces scientific uncertainty so appropriate management measures can be employed	Limited management measures available to minimise interaction despite modelling to fully predict interaction
The potential wider or secondary effects on protected or sensitive sub-littoral seabed due to removal or alteration of energy flow arising from devices and moorings or support structures.	All receptors	Operation & maintenance	Site selection	Design feature	Minimises significance of interaction	None identified
Modifications to prey distribution and abundance (to include for other receptors) resulting in changes to foraging behaviour	Marine mammals, diving birds, and fish	Operation & maintenance	Site selection	Design feature	Minimises significance of interaction	None identified

Table 3: Critical analysis of management measures related to the interaction of 'changes in tidal flow, flux and turbulence structures

Dissipation of wave energy (relevant to wave only)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
The potential wider or secondary effects on protected or sensitive seabed due to removal or alteration of energy flow arising from devices and moorings or support structures.	Benthic invertebrates	Operation & maintenance	Benthic and intertidal surveys focused on indicator species, species assemblage, community structure and ecosystem function.	Monitoring	Reduce scientific uncertainty	Determining impacts against natural variability may be difficult.
The potential wider or secondary effects on protected or sensitive seabed due to removal or alteration of energy flow arising from devices and moorings or support structures.	Benthic invertebrates	Operation & maintenance	Modelling to predict the interaction between wave energy and animals	Monitoring	Reduces scientific uncertainty so appropriate management measures can be employed	Limited management measures available to minimise interaction despite modelling to fully predict interaction

Table 4: Critical analysis of management measures related to the interaction of 'dissipation of wave energy'

Collision risk (relevant to tidal only)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Potential for collision with turbine blades	Marine mammals	Operation & maintenance	Install a 'detect and shut-down' system using active sonar and other appropriate monitoring equipment	Mitigation	This could reduce/remove risk of collision with moving blades	<p>This could affect power production, is expensive to implement and does not help reduce scientific uncertainty regarding the risk</p> <p>uncertainty around effects of sonar on sensitive species</p> <p>Not certain how often 'shut-downs' would be required.</p> <p>Detection systems are currently insufficient to detect animals (in particular at array scale)</p> <p>As this will affect power production, it could undermine the investability of a project.</p>
Potential for collision with turbine blades	Marine mammals	Operation & maintenance	Install a 'detect and slow-down' system using active sonar and other appropriate monitoring equipment	Mitigation	This could reduce/remove risk of collision with moving blades	<p>This could affect power production, is expensive to implement and does not help reduce scientific uncertainty regarding the risk</p> <p>uncertainty around effects of sonar on sensitive species</p> <p>Not certain how often 'slow-downs' would be required.</p> <p>Detection systems are currently insufficient to detect animals (in particular at array scale)</p> <p>As this will affect power production, it could undermine the investability of a project.</p>

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Potential for collision with turbine blades	Marine mammals	Operation & maintenance	Install a 'detect and deter' system using a combination of active sonar and acoustic deterrent device (ADD)	Mitigation	This could reduce likelihood of collision with moving blades although the efficacy of ADDs in these environments is unknown	This is expensive to implement and it is unknown if deterrent systems will help reduce risk Effects of ADDs on sensitive species Detection systems are currently insufficient to detect animals (in particular at array scale)
Interaction: Potential for collision with turbine blades	Marine mammals	Operation & maintenance	Install acoustic deterrent devices (ADDs)	Monitoring	This could reduce likelihood of collision with moving blades although the efficacy of ADDs in these environments is unknown	This is expensive to implement and it is unknown if deterrent systems will help reduce risk Effects of ADDs on sensitive species
Interaction: Potential for collision with turbine blades	Marine mammals, fish and seabirds	Operation & maintenance	Environmental monitoring to detect collision events	Monitoring	Understand avoidance behaviour, nature of interactions and outcome of collision events.	Can be a high cost associated with this Unclear how much monitoring will be required to fully understand this risk Practicalities of monitoring; technology is not advanced enough yet to do this efficiently. Data mortgage ³ Power supply availability - hard-wired vs. battery; power is required for monitoring and power availability can present logistical, financial and technical challenges Interaction between equipment - e.g. multibeam sonar/ ADCP/ echosounder; there can be interaction between monitoring equipment which can present challenges in monitoring Certain equipment used such as PAM may actually effect behaviour themselves.
Interaction: Potential for collision with turbine blades	Marine mammals, fish and seabirds	Operation & maintenance	Implement a 'soft start' approach during cut-in	Mitigation	This could reduce risk by allowing animals time to move away from the turbine. Low cost option, adopted for other activities (e.g. piling)	Unclear if this offers additional mitigation as many devices power up gradually anyway.
Interaction: Potential for collision with turbine blades	Marine mammals, fish and seabirds	Operation & maintenance	Environmental monitoring to better understand near-field behaviour and avoidance	Mitigation	This will help reduce scientific uncertainty	Can be a high cost associated with this Unclear how much monitoring will be required to fully understand this risk Practicalities of monitoring; technology is not advanced enough yet to do this efficiently.

³ Data mortgage is the concept of generating data more quickly than it can be analysed

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
						Data mortgage ⁴ Power supply availability - hard-wired vs. battery; power is required for monitoring and power availability can present logistical, financial and technical challenges Interaction between equipment - e.g. multibeam sonar/ ADCP/ echosounder; there can be interaction between monitoring equipment which can present challenges in monitoring Certain equipment used such as PAM may actually affect behaviour themselves.
Interaction: Potential for collision with turbine blades	Marine mammals, fish and seabirds	Operation & maintenance	Reduce maximum blade tip speed	Mitigation	This could reduce the likelihood/consequence of potential collision events	Potential impacts on power production. Control mechanism of turbine blade speed unclear. May cause increased fatigue
Interaction: Potential for collision with turbine blades	Marine mammals, fish and seabirds	Operation & maintenance	Selective structural and blade coatings i.e. colours to aide detection	Mitigation	Unknown - it is possible that this will aid detection of subsea structures and help reduce risk	This could result in 'attraction', increasing risk of collision Uncertainty around how animals use visual cues. Other sensory organs are often more important for fish & seals Use of such measures may be limited to conform with IALA standards
Interaction: Potential for collision with turbine blades	Marine mammals, fish and seabirds	Operation & maintenance	Design proportion of swept area to structure area to minimise collision risk		This could reduce the likelihood/consequence of potential collision events	Can be a high cost associated with this Can present financial/ logistical/ design challenges to technology developer to alter design of device

Table 5: Critical analysis of management measures related to the interaction of 'collision risk'

Vessel disturbance or collision (relevant to wave & tidal)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Potential for disturbance from project vessels	Birds on water	All phases	Do not break up or 'flush' rafts of birds	Mitigation	Reduces potential effects. Relatively low-cost measure.	Effectiveness of mitigation unclear.
Potential for disturbance from project vessels	Birds on water & marine mammals	All phases	Adhere to minimum approach distances for vessels on approach to marine mammals and birds	Mitigation	Reduces potential effects. Relatively low-cost measure.	None identified

⁴ Data mortgage is the concept of generating data more quickly than it can be analysed

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Potential for disturbance from project vessels	Shore-nesting birds	All phases	Avoidance of sensitive shore nesting areas during sensitive periods with appropriate clearance distance.	Mitigation	Reduces potential effects. Relatively low-cost measure.	None identified
Potential for disturbance from project vessels	Marine mammals	All phases	Reduce speed and maintain steady course when animal is sighted	Mitigation	Reduces potential effects. Relatively low-cost measure.	None identified
Disturbance at seal haul-out sites from project vessels	Seals	All phases	Avoid transiting within 500m of designated seal haul outs	Mitigation	Reduces potential effects. Relatively low-cost measure.	None identified
Potential for disturbance from project vessels	Birds on water	All phases	Vessel transit route: defining routes to avoid sensitive sites and to only disturb one route	Mitigation	Reduces potential effects. Relatively low-cost measure. This is measurable and definable.	None identified
Potential for disturbance from project vessels	Marine mammals	All phases	Care will be taken to avoid splitting up groups and mothers and young	Mitigation	Reduces potential effects. Relatively low-cost measure.	None identified
Potential for disturbance from project vessels	Marine mammals & birds on water	All phases	Vessel speed limitation to and from site	Mitigation	Reduces potential effects. Relatively low-cost measure.	None identified

Table 6: Critical analysis of management measures related to the interaction of 'vessel disturbance or collision'

Displacement (relevant to wave & tidal)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Potential displacement of essential activities due to the presence of devices and associated moorings / support structures	All receptors	Operations & Maintenance	Site selection (taking into account cumulative impact of other developments)	Design feature	Minimises risk of development causing displacement by avoiding migratory routes or other important sites	None identified
Potential displacement of essential activities due to the presence of devices and associated moorings / support structures	All receptors	All phases	Timing of installation and decommissioning & marine operations to avoid times of particular sensitivity (e.g. breeding)	Mitigation	Minimises risk of development causing displacement by avoiding works during sensitive times	Can be disruptive and hence costly to developer
Potential displacement of essential activities due to the presence of devices and associated moorings / support structures	All receptors	All phases	Array/ mooring configuration designed to avoid migratory routes or other important sites	Design feature	Minimises risk of development creating displacement by avoiding migratory routes or other important sites	May be inconsistent with optimal layout of the development for exploitation of the energy source Can be a costly measure when scaling up to larger arrays
Potential displacement of essential activities due to the presence of devices and associated moorings / support structures	All receptors	All phases	Baseline surveys should focus on functional importance of project areas and association of wildlife with hydrodynamic features and microhabitats.	Design feature	Project design might be better informed to reduce or avoid such effects	None identified

Table 7: Critical analysis of management measures related to the interaction of 'displacement'

Electromagnetic fields (EMF; relevant to wave & tidal)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Impacts of electromagnetic fields from subsea cables on sensitive species	Migratory fish & elasmobranchs	Operation & maintenance	Install cable protection/ armour/ rock placement/ other cable protection	Design feature	<p>Reduce the level of EMF to surrounding water column and therefore any potential effects</p> <p>Reduces 'snagging risk' for vessels</p> <p>Creation of artificial habitat</p>	<p>The implication of this measure may have an impact on surrounding benthic habitats and sensitive species</p> <p>Creation of artificial habitat may cause aggregation effect causing greater impact of EMF</p> <p>Increased cost to project</p> <p>Reduced possibilities of decommissioning in future</p>
Impacts of electromagnetic fields from subsea cables on sensitive species	Benthic invertebrates	Operation & maintenance	Install cable protection/ armour/ rock placement/ other cable protection	Design feature	<p>Reduce the level of EMF to surrounding water column and therefore any potential effects</p> <p>Reduces 'snagging risk' for vessels</p> <p>Creation of artificial habitat leading to greater fecundity in species</p>	<p>The implication of this measure may have an impact on surrounding benthic habitats and sensitive species</p> <p>Creation of artificial habitat may cause aggregation effect causing greater impact of EMF</p> <p>Uncertainty around the effect of EMF on benthic species. Hence uncertainty around the need for and efficacy of this measure</p> <p>Increased cost to project</p> <p>Reduced possibilities of decommissioning in future</p> <p>Direct disturbance/ loss if benthic communities</p>
Impacts of electromagnetic fields from subsea cables on sensitive species	Migratory fish & elasmobranchs	Operation & maintenance	Use of 3-phase cables instead of DC cables	Design feature	Reduce the level of EMF to surrounding water column and therefore any potential effects	Potential commercial and technical feasibility issues.
Impacts of electromagnetic fields from subsea cables on sensitive species	Benthic invertebrates	Operation & maintenance	Use of 3-phase cables instead of DC cables	Design feature	Reduce the level of EMF to surrounding water column and therefore any potential effects	<p>Potential commercial and technical feasibility issues.</p> <p>Uncertainty around the effect of EMF on benthic species. Hence uncertainty around the need for and efficacy of this measure</p>
Impacts of electromagnetic fields from subsea cables on sensitive species	Migratory fish & elasmobranchs	Operation & maintenance	Bundle cables together to reduce field vectors	Design feature	Reduce the level of EMF to surrounding water column and therefore any potential effects	<p>Less redundancy in system.</p> <p>Potential commercial and technical feasibility issues.</p> <p>Greater costs associated with not laying direct cable paths</p>
Impacts of electromagnetic fields from subsea cables on sensitive species	Benthic invertebrates	Operation & maintenance	Bundle cables together to reduce field vectors	Design feature	Reduce the level of EMF to surrounding water column and therefore any potential effects	<p>Less redundancy in system.</p> <p>Potential commercial and technical feasibility issues.</p> <p>Uncertainty around the effect of EMF on benthic species. Hence uncertainty around the need for and efficacy of this measure</p>

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
						Greater costs associated with not laying direct cable paths
Impacts of electromagnetic fields from subsea cables on sensitive species	Migratory fish & elasmobranchs	Operation & maintenance	Bury or HDD cables where possible and viable	Design feature	Reduce the level of EMF to surrounding water column and therefore any potential effects Reduces 'snagging risk' for vessels	The implication of this measure may have an impact on surrounding benthic habitats and sensitive species Can be very challenging or impossible at sites where seabed tends to be rocky Additional expense to the project. Permanent damage to seabed. Reduced possibility of ever decommissioning.
Impacts of electromagnetic fields from subsea cables on sensitive species	Benthic invertebrates	Operation & maintenance	Bury or HDD cables where possible and viable	Design feature	Reduce the level of EMF to surrounding water column and therefore any potential effects Reduces 'snagging risk' for vessels	The implication of this measure may have an impact on surrounding benthic habitats and sensitive species Uncertainty around the effect of EMF on benthic species. Hence uncertainty around the need for and efficacy of this measure Can be very challenging or impossible at sites where seabed tends to be rocky Additional expense to the project. Permanent damage to seabed. Reduced possibility of ever decommissioning.

Table 8: Critical analysis of management measures related to the interaction of 'displacement'

Entanglement (relevant to wave & tidal)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Potential for marine animals to become entangled in device mooring lines and cables	Cetaceans and basking shark	Operation & maintenance	Maintain taut or adopt 'bungee' mooring lines	Design feature	Remove/reduce risk of entanglement Regular inspections can provide operational insight into condition	Mooring design driven by technical and commercial consideration. Regular ROV/ dive or drop-down cameras inspections required
Potential for marine animals to become entangled in device mooring lines and cables	Cetaceans and basking shark	Operation & maintenance	Cable design with maximum bend radius	Design feature	Remove/reduce risk of entanglement	Mooring design driven by technical and commercial consideration.
Potential for marine animals to become entangled in device mooring lines and cables	Cetaceans and basking shark	Operation & maintenance	Install tension sensors on mooring lines	Monitoring	Informs of problem with mooring lines allowing rectification Cost per unit	Additional cost and control system integration requirement.

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
						Load from entangled animal is likely to be smaller than the device loading on the moorings. Uncertainty of the efficacy of this measure
Potential for marine animals to become entangled in device mooring lines and cables	Cetaceans and basking shark	Operation & maintenance	Fishing debris detected during routine inspections of mooring lines and cables will be removed	Mitigation	Remove/reduce risk of entanglement Low cost measure, implemented as part of standard O&M procedures. Regular monitoring will benefit system performance in addition to addressing environmental risks (e.g. early detection of damage or failures in the system)	None identified
Potential for marine animals to become entangled in device mooring lines and cables	Cetaceans and basking shark	Operation & maintenance	Ensure standard notifications of loss of fishing gear in region notified to operators. Reporting of entanglement events.	Monitoring	Good practice for emergency preparedness	Chances of lost fishing gear being reported is reportedly low
Potential for marine animals to become entangled in device mooring lines and cables	Cetaceans and basking shark	Operation & maintenance	Routine inspections of mooring lines. Implement features into existing control systems to detect entanglement events.	Monitoring	Remove/reduce risk of entanglement. Likely to be required as part of the technical monitoring of the device and therefore not an additional cost	Could be a costly measure for technology developers
Potential for marine animals to become entangled in device mooring lines and cables	Cetaceans and basking shark	Operation & maintenance	Minimise the number of mooring lines	Design feature	Reduce risk of entanglement.	Could be a costly measure for technology developers

Table 9: Critical analysis of management measures related to the interaction of 'entanglement'

Entrapment (relevant to wave & tidal)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Potential risk of entrapment within device chambers and mooring arrays	All receptors	Operation & maintenance	Regular ROV/ drop down camera surveys to establish occurrence of entrapment	Mitigation	Early detection of entrapment	Additional cost

Table 10: Critical analysis of management measures related to the interaction of 'entrapment'

Habitat creation (relevant to wave & tidal)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
The introduction of infrastructure and artificial substrates will provide habitat and artificial refuges	All receptors	Operation & maintenance	Monitor near-field behaviours	Monitoring	Reduces scientific uncertainty around collision risk, displacement and other impacts Increased value/ fecundity of commercially important species	This type of monitoring can be expensive and difficult to deliver in practice May require additional licensing (e.g. echosounders)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
The introduction of infrastructure and artificial substrates will provide potential roosting habitat	Roosting birds	Operation & maintenance	Monitor use of device as a roosting platform	Monitoring	Reduces scientific uncertainty around collision risk, displacement and other impacts Monitoring is relatively inexpensive to carry out	Data mortgage ⁵
The introduction of infrastructure and artificial substrates may generate additional habitat diversity.	Benthic	Operation & maintenance	Structure colonisation and biofouling surveys	Monitoring	Informs understanding of potential for increased prey availability and ecological diversity	Cost associated with monitoring

Table 11: Critical analysis of management measures related to the interaction of 'habitat creation'

Introduction of marine non-native species (MNNS; relevant to wave & tidal)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Potential for introduction of MNNS which can have an adverse impact on the native species at the site	All receptors	All phases	Compliance with all relevant guidance (including IMO guidelines) regarding ballast water management and transfer of non-native species	Compliance	Reduce/remove risk of transfer and settlement of non-native species	None identified
Potential for introduction of MNNS which can have an adverse impact on the native species at the site	All receptors	All phases	Establish and implement a Biofouling Management Plan	Mitigation	Reduce/remove risk of transfer of non-native species	Lack of industry specific guidance
Potential for introduction of MNNS which can have an adverse impact on the native species at the site	All receptors	All phases	Adhere to appropriate measures when jettisoning ballast water	Design feature	Reduce/remove risk of transfer of non-native species	None identified
Potential for introduction of MNNS which can have an adverse impact on the native species at the site	All receptors	All phases	Source vessels locally	Design feature	Reduce/remove risk of transfer of non-native species	None identified

Table 12: Critical analysis of management measures related to the interaction of 'introduction of marine non-native species'

Lighting (relevant to wave & tidal)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Potential for lighting to adversely affect nocturnal and migratory species	Seabirds	Operation & maintenance	Consider type, colour and use of lighting during design and consultation with navigational stakeholders	Design feature	A targeted lighting plan may have the potential to reduce impacts on sensitive species but navigational interests need to be considered at all times	Navigational safety considerations will take priority over implementation of ecological aspects

⁵ Data mortgage is the concept of generating data more quickly than it can be analysed



Potential for lighting to adversely affect nocturnal and migratory species	Seabirds	Operation & maintenance	Monitoring effects on animals.	Monitoring	Reduce scientific uncertainty	Can be difficult to detect change as a result of interaction as opposed to natural variability
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Table 13: Critical analysis of management measures related to the interaction of 'lighting'

Loss of seabed habitat (relevant to wave & tidal)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Direct loss of protected or sensitive sub-littoral seabed communities due to the presence of devices associated moorings or support structures on the seabed	Benthic invertebrates and demersal fish	Construction & decommissioning	Micrositing of offshore infrastructure to avoid sensitive habitats.	Design feature	This could reduce/remove effects on sensitive habitats. Low cost measure at single device or small-scale array.	None identified
Direct loss of protected or sensitive sub-littoral seabed communities due to the presence of devices associated moorings or support structures on the seabed	Benthic invertebrates and demersal fish	Construction & decommissioning	Site selection to avoid sensitive or protected sub-littoral seabed communities	Design feature	This could reduce/remove effects on sensitive habitats.	None identified
Direct loss of protected or sensitive sub-littoral seabed communities due to the presence of devices associated moorings or support structures on the seabed	Benthic invertebrates and demersal fish	Construction & decommissioning	Minimise footprint of anchors / foundations	Design feature	This could reduce effects on sensitive habitats	May impact technical considerations
Direct loss of protected or sensitive sub-littoral seabed communities due to the presence of devices associated moorings or support structures on the seabed	Benthic invertebrates and demersal fish	Construction & decommissioning	Cable protection management measures to ensure that any rock placement that is required will be kept to a minimum to reduce seabed disturbance	Design feature	This could reduce effects on sensitive habitats	Additional cost
Direct loss of protected or sensitive sub-littoral seabed communities due to the presence of devices associated moorings or support structures on the seabed	Benthic invertebrates and demersal fish	Construction & decommissioning	Use of local materials in cable armouring		Lost seabed is replaced with same material. Minimises loss of habitat	None identified

Table 14: Critical analysis of management measures related to the interaction of 'loss of seabed habitat'

Pollution impacts (relevant to wave & tidal)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Potential for accidental or unplanned events which could lead to pollution of the marine environment	All receptors	All phases	Physical Containment systems including bulk heads, closed circuit systems, pressure relief systems, bunding	Design feature	Reduces risk of pollution escaping from structure.	None identified
Potential for accidental or unplanned events which could lead to pollution of the marine environment	All receptors	All phases	Material selection - lubricants, coolants, hydraulic fluids etc. selected with low ecotoxicity levels and biodegradable	Mitigation	Reduces/removes risk of pollution from materials which may have escaped structure.	Use of lower toxicity materials may compromise performance, or impact other technical issues (e.g. fluid changes).

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
Potential for accidental or unplanned events which could lead to pollution of the marine environment	All receptors	All phases	Where rock placement is used, ensure clean rock is used	Mitigation	Reduces/removes risk of pollution from materials	None identified
Potential for accidental or unplanned events which could lead to pollution of the marine environment	All receptors	All phases	Management: Establish and implement a Pollution Control Plan / Ship Oil Pollution Emergency Plans (SOPEPs) Compliance with International Maritime Organisation (IMO) and Maritime Coastguard Agency (MCA) codes for the prevention of pollution.	Mitigation	Reduces risk of any pollution event and ensures that contingency plans are in place. Demonstrates compliance with environmental management systems.	None identified

Table 15: Critical analysis of management measures related to the interaction of 'pollution impacts'

Underwater noise (relevant to wave & tidal)

Interaction	Receptor	Phase of Project	Environmental management measures	Management measure category	Effect of Management Measure - Advantages	Effect of Management Measure - Challenges
The potential effects from underwater noise generated during installation/ construction (excluding piling)	Marine mammals and seabirds and fish	Construction & decommissioning and pre-construction baseline surveys (e.g. Geophysical works)	Avoid/limit 'noisy works' within close proximity to sensitive sites i.e. known seal haul outs and important cliff nesting sites, during sensitive periods, defining appropriate clearance distances where necessary.	Mitigation	This could reduce potential effects on sensitive species during sensitive periods.	This could increase project construction timescales e.g. if continuous drilling time is restricted or specific periods need to be avoided
The potential effects from underwater noise generated during installation/ construction (excluding piling)	Marine mammals and fish	Operation & maintenance	Measure noise generated by device(s) during operation to better understand the potential effects on sensitive species	Monitoring	Measured noise levels can be correlated with threshold values of relevant species and baseline noise levels of the site to determine impact and need for adaptive management measures.	Can be complex and costly to undertake this type of monitoring in high energy environments Data and analysis have requirement for acoustic experts.
The potential effects from underwater noise generated during installation/ construction (excluding piling)	Marine mammals and fish	All phases	Limit vessel speed	Mitigation	Reduces potential effects. Relatively low-cost measure.	None identified

Table 16: Critical analysis of management measures related to the interaction of 'underwater noise'



4 Conclusions

As can be seen in the tables above, there is a requirement for further monitoring and testing of many of these environmental management measures to reduce uncertainty around their efficacy. The reason for this is the relatively low number of deployments in the wave and tidal industry to date, leading to limited opportunities to utilise these management measures, collect data on their efficacy and to better understand the advantages and challenges associated with their implementation, particularly within the context of pre-commercial and commercial projects. There has also been a lack of specific funding to support this work, and hence the SEAWave project as funded by EASME through EMFF is vital in reducing this uncertainty.

It is also flagged during the interviews that study of these interactions and hence efficacy of management measures can be complex. Differentiating between natural variability and potential direct impacts of the introduction of a man-made structure often requires significant statistical power and can present a challenge when working on small scale arrays or single device deployments.

Further data collection will be required to gain a more in depth understanding of the interactions between marine energy devices and marine animals and habitats. Additionally, it is vitally important that data is analysed and reported in order for others to learn from this. It has been noted that this is also important where management measures have not worked as planned. Reporting of this will aid in reducing uncertainty and improving on these management measures in future developments.

Two general environmental management measures were raised during the consultation process that should be considered in relation to all impacts:

1. The use of an Ecological Clerk of Works is often required as a licence/consent condition and one of the key purposes of this role is to ensure the implementation of any management measures that were proposed in the consenting reports such as Environmental Impact Statement or Environmental Management Plan⁶ or those that are set out in Environmental Management Plans/Construction Environmental Management Document.
2. Baseline data gathered to inform project design and consenting activities could be used alongside data and information collected during construction, operation, maintenance and decommissioning/removal to reduce uncertainty around potential effects and the efficacy of environmental management measures.

It is acknowledged that there is more work to do in order to better understand the interactions between marine energy developments and marine animals and habitats; and the management measures to minimise the deleterious effects of these interactions. However, it is also acknowledged that it will be challenging to ever show that there is no negative impact on marine animals and habitats as there will always be 'unknown unknowns' and it is impossible to prove that something will 'never' occur.

At this time, the partners of the SEA Wave project, in collaboration with ORJIP Ocean Energy would like to actively encourage feedback on the information presented in this report.

⁶ Also known as a Project Environmental Monitoring Programme



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If you have additional experience in this field and would like to add to this critical analysis, please contact the team using the information below:

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