Guidance document

Use of Static Passive Acoustic Monitoring (PAM) for monitoring cetaceans at Marine Renewable Energy Installations (MREIs) for Marine Scotland

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Executive Summary

This guidance document provides advice aimed at developers of marine renewable energy installations (MREIs) on the use of static passive acoustic monitoring (PAM) devices for monitoring vocalising cetaceans around MREIs. The document considers static passive acoustic monitoring (static PAM) for wind farms, tidal stream devices and wave energy converters. In UK waters, static PAM is most appropriate for monitoring small cetacean species such as harbour porpoises (*Phocoena phocoena*) and dolphin species (such as bottlenose dolphins, *Tursiops truncatus*; common dolphins, *Delphinus delphis*; and white-beaked dolphins, *Lagenorhynchus albirostris*). Static PAM methods allow for continuous autonomous monitoring of small cetacean occurrence at MREI sites, and are thus one of the few approaches available to describe seasonal trends in habitat use, as well as direct measures of impact resultant from MREI activities. This document provides guidance on static PAM survey design, deployment and retrieval, and data analysis.

Introduction

Marine renewable energy installations (MREI), whether wind, wave or tidal stream, are likely to effect the marine ecosystem into which they are introduced. Cetaceans form a charismatic and legally protected component of the marine ecosystem, and so require particular attention during all stages of MREI development. The most common cetacean in UK waters is the harbour porpoise (*Phocoena phocoena*), but other species found in North East Atlantic shelf waters (<200 m depth) that can be detected using passive acoustic monitoring (PAM) devices include bottlenose dolphins (*Tursiops truncatus*), common dolphins (*Delphinus delphis*), white-beaked dolphin (*Lagenorhynchus albirostris*), and less regularly, Risso's dolphin (*Grampus griseus*), killer whales (*Orcinus orca*) and Atlantic white-sided dolphins (*Lagenorhynchus acutus*). Other common cetacean species occupying shelf waters includes the minke whale (*Balaenoptera acutorostrata*), however, they vocalise infrequently in these environments and as such acoustic monitoring provides poor oversight on their distribution and behaviour (nor is it useful for grey seals, *Halichoerus grypus,* or harbour seals, *Phoca vitulina*).

Legislation

Cetaceans are protected under a range of National and International legislation. Under the EU Habitats Directive all cetaceans are classed as European Protected Species (EPS), making it an offence to disturb any animal within 12 nautical miles of the UK mainland (Marine Scotland, 2014) and to cause significant outside of 12 nautical miles in Scottish waters (JNCC, 2008; EU Habitats Directive Offshore Marine Conservation (Natural Habitats, & c.) Regulations, 2007). In addition, harbour porpoises and bottlenose dolphins are provided additional protection within Special Areas of Conservation (SACs) under Annex II of the Habitats Directive.

If the impact footprint of an MREI is likely to overlap an area or resources used by individuals with clear links to any SAC, then Likely Significant Effect (LSE) may be advised by the statutory nature conservation agency (SNCA – SNH in Scotland). Should this be the case a developer is required to conduct a Habitats Regulation Appraisal (HRA) to provide information which the competent authority (Marine Scotland for Scottish waters) could use in an Appropriate Assessment (AA). The AA determines whether an MREI proposal will have an adverse effect on the integrity of the SAC, when judged against the conservation objectives for the site (Marine Scotland, 2012).

Potential impacts of MREIs on cetaceans

Since relevant legislation is framed towards minimising the risks of killing, injuring, or disturbing cetaceans, any monitoring program should aim to provide sufficient data to support risk assessments, and the decision making process. This is likely to include objectives such as baseline site characterisation, assessing occupancy or population level relative to an agreed target or baseline, or assessing the effectiveness of any mitigation measures put in place during any part of the MREI development (whether construction, deployment, operation or decommissioning). MREIs may impact cetaceans in a number of ways including (based on Macleod et al 2011):

- Collision – with the device(s) or entanglement in cables associated with the device(s).
- Acoustic impact – whether during construction (pile driving, increased boat traffic, & other construction activities such as geophysical surveys), or operation.
- Displacement/barrier effects – arrays of devices may act as barriers to migrating or travelling animals, potentially acute for animals travelling through narrow tidal channels.
- Habitat alteration – whether through loss of habitat, or 'improvement' when devices act as artificial reefs or Fish Aggregating Devices (FADs), thereby inadvertently improving foraging opportunities for cetaceans.
- Changes in water flow & turbidity – which may affect the ability of animals to forage and the distribution of their prey.
- Electromagnetic fields (EMF) – may affect navigation cues, though there is little knowledge of their effect on cetaceans and cetaceans lack specific electro-sensing organs.

Risks to cetaceans from these impacts will depend on a number of factors including device type (e.g. collision risk associated with tidal turbines; Wilson et al. 2013b), construction method (e.g. acoustic impacts of pile driving, e.g. Carstensen et al. 2006), habitat (e.g. devices in narrow tidal channels may have a higher risk of resulting in a barrier to movement), and location (e.g. risks are more of a concern close to SAC populations and breeding grounds).

Questions that can be answered by static PAM

'Monitoring' can be divided into two different phases; site characterisation surveys and post-consent monitoring (Macleod et al. 2011). The purpose of site characterisation is to gather information on the species present, their distribution, abundance and behaviour at the development site to address several regulatory requirements: (i) Environmental Impact Assessment (EIA); (ii) assess whether any EPS under Annex IV of the Habitats Directive are present; (iii) assess whether developments may affect SAC populations (HRA). Monitoring may not be required at this stage if there is sufficient information available.

The purpose of post-consent monitoring (or 'impact monitoring'; ICES 2013) is two-fold: firstly to assess the accuracy of the predictions made in the EIA; and secondly to assess the impact of the development on species and the effectiveness of any mitigation measures (Macleod et al. 2011).

Static PAM devices can be used in both phases to potentially answer questions such as (Macleod et al. (2011) and ICES (2013)):

- Are any vocalising cetaceans present in the development area? (*characterisation*)
- What is the spatial and temporal distribution of vocalising cetaceans in the development area? (*characterisation*)
- Is there a significant difference in vocalisation rate between baseline and either construction, operation or decommissioning? (*post-consent*)
- Is the detected change limited to the development footprint or over a wider area? (*post-consent*)
- Does the impact change with time or distance? (*post-consent*)

With post-consent monitoring an additional aim may be to assess these above questions at the population level (i.e. do any changes attributable to the development result in changes at a population level?) (Bailey et al. 2014). However, it is unlikely that any project in isolation would be able to answer these questions, so any monitoring data should be capable of being fed into higher level population models, such as the interim Population Consequences of Disturbance (PCoD) model (Harwood et al. 2014, Lusseau et al. 2012). In order to gather more scientifically robust data, it may be useful to target monitoring of particular impacts at specific sites, rather spreading the same effort across several sites, and having none with sufficient power to address the key questions. High quality data collected from these sites could then be used to inform impact assessments of similar activities in other areas.

Static Passive Acoustic Monitoring

PAM is a widely used technique for detecting vocalising marine mammals during anthropogenic activities such as seismic surveying for oil and gas (Parsons et al. 2009; Thompson et al. 2013; Pirotta et al. 2014) and wind farm pile driving (e.g. Brandt et al. 2011, Thompson et al. 2010), or for research purposes (Küsel et al. 2011). It is appropriate for monitoring marine mammal species that vocalise frequently, such as harbour porpoises and dolphin species. It is, however, of little value for monitoring species with low vocalisation rates, such as seals and baleen whales, including minke whales which are often encountered in inshore waters. Static PAM is usually carried out from single or multiple static locations, although we include drifting acoustic devices in this guidance (Wilson et al. 2013a).

Vocalisation characteristics

Odontocetes (dolphins and porpoises) use two different forms of vocalisation: whistles and echolocation clicks. Whistles usually span across wide frequency ranges, and are believed to be used for communicating between animals. These sounds are omnidirectional and can be heard over large distances depending on oceanographic and seabed conditions that influence sound propagation (e.g. up to 25 km for bottlenose dolphin whistles in low sea states, Janik 2000). Echolocation clicks are thought to be mainly used for navigation and finding prey. Clicks are produced in a very narrow directional beam, and tend to be at high frequencies (>20kHz; Au 1993) so typically propagate only a few hundred metres.

Each species produces sound differently, using different frequency ranges or sound form (e.g. different whistle types). For example, white-beaked dolphin's echolocation clicks have been recorded at frequencies up to 250 kHz (Rasmussen & Miller 2002), whilst killer whale echolocation clicks tend to be at lower frequencies, down to 8 kHz (Simon et al. 2007). Harbour porpoises do not whistle, and only produce echolocation clicks within the range of 110-150 kHz (Richardson et al. 1995). Species should in theory be distinguishable on the basis of their vocalisations, but in practice this is difficult due to both the lack of data on vocalisation properties of different species and similarities in vocalisations between closely related species (e.g. between the two *Lagenorhynchus* species – white-sided and white-beaked dolphins) and the habitats in which the vocalisations occur. It is currently possible to distinguish between harbour porpoise clicks and dolphin clicks, but it remains difficult to distinguish among dolphin species. Recently methods have been developed to distinguish between bottlenose dolphins and other dolphin species in the Moray Firth from their whistles (Gillespie et al. 2013) so it may be possible to extend this to other bottlenose dolphin populations around the UK.

Device types

There are two broad types of static PAM currently in widespread use to monitor vocalising cetaceans: click detectors (such as CPODs, Chelonia Ltd; and AQUAclick, Aquatec Group), and sound recorders (such as SM3Ms, Wildlife Acoustics; and AMARs, JASCO; Loggerhead Instruments Archival Recorder, and the Seiche Measurement devices) (Table 1). In the near future autonomous detectors will also be available that can detect and classify multiple vocalisation types whether whistles or clicks (e.g. PAMBuoy, St Andrews Instrumentation). Devices that are able to automatically identify and classify potential vocalisation sounds (such as the click detectors) allow for longer deployment times due to the smaller amount of data storage required. These automated click detectors tend to be deployed for much longer than continuous autonomous sound recorders, as they can record continuously without need for a duty cycle (e.g. CPODs can be deployed for 3-4 months at a time). Deployment times of sound recorders, and click detectors to a lesser extent, are limited by various factors:

- *Frequency* – to monitor at high frequencies (e.g. up to the 150 kHz produced by harbour porpoises) faster processors are required (with their associated power demands) and large amounts of data are generated (e.g. to record at 150 kHz a sampling rate of at least 300 kHz is required (the Nyquist rate) resulting in around 300 Mbytes/second), thus quickly exhausting available memory. The higher the recorded frequency, the shorter the deployment time if continuous sound recording is carried out, typically duty cycling is used to extend deployment durations from days to weeks/months.
- *Memory size* – as a consequence, the larger the device's memory capacity is, the longer the device can be deployed e.g. AMAR can store up to 1.76 TB, the SM3M can store up to 1 TB (Table 1).
- *Battery size* – similarly, the larger the battery capacity, the longer the deployment time (battery capacity is more limiting for autonomous detectors such as click detectors than continuous recorders, the latter which tend to be more memory limited).
- *Duty cycle* – the duty cycle is a method of prolonging deployment time by sub-sampling in time. For example, only recording for 10 minutes every hour. The duty cycle needs careful selection when used for monitoring since sub-sampling in this way may result in animals being missed as they pass through the area during the non-sampled period.

Both click detectors and acoustic recorders have their advantages and disadvantages (Table 2). However a combination of both click detectors (for long term monitoring) and sound recorders (for noise monitoring and identification of echolocation clicks to species) is currently likely to be the optimum solution in areas where multiple cetacean species are likely to be encountered. This is the approach currently being adopted at Wave Hub, FAB (Falmouth Bay), in the Moray Firth, and along the east coast of Scotland. For example, the population of bottlenose dolphins in the Moray Firth is protected within an SAC, so it is important to be able to distinguish between harbour porpoises, bottlenose dolphins and other species of dolphins in this area to evaluate impacts on the SAC population. In this area it is now possible to distinguish among these cetacean groups by using a combination of click detectors and sound recorders with post-processing through PAMGUARD (Gillespie et al. 2013).

Table 1 – currently available high frequency static acoustic recorders, with indication of cost (£ = up to £4,000; ££ = £4,000 - £10,000; £££ = over £10,000; POR = Price On Request)

Device	Manufacturer & website	Frequency monitored	Memory	Deployment duration	Cost
Click detectors					
Aquaclick	Aquatec http://www.aquatecgroup.com/	130kHz	8MB	2 weeks	£
CPOD	Chelonia http://www.chelonia.co.uk/	20-160kHz	4GB	> 4 months	£
Sound recorders					
AMAR G3	JASCO http://www.jasco.com/	1-150kHz	1.76TB	< 1 year$^{\beta}$	£££
DSG	Loggerhead Instruments http://loggerheadinstruments.com/	< 80kHz	128GB	< 273 days$^{\beta}$	£-££
RUDAR	Cetacean Research Technology http://www.cetaceanresearch.com/	< 193kHz	Variable	$^{\beta}$	POR
BA-SDA14	RTSYS http://www.rtsys.eu/	< 900kHz	128GB$^{\gamma}$	12 days$^{\delta}$	POR
SM3M ultrasonic	Wildlife acoustics http://www.wildlifeacoustics.com/	2-192kHz	1TB	>26 days $^{\beta}$	££
Remote Buoy	Seiche measurements http://www.seiche.eu.com/	0.01-200kHz	N/A	to specification	POR

$^{\beta}$ dependent on sample rate (frequency), duty cycle and battery size; $^{\gamma}$ or up to 2TB using a hard drive; $^{\delta}$ or real time within 3km (WiFi).

Currently most devices require periodic retrieval to download the data. However, there are some devices on the market which can transmit data via WiFi (e.g. RTSYS system), radio frequencies (e.g. Seiche Measurements remote buoy), or via other technology such as satellite (e.g. PAMBUOY, St Andrews Instrumentation Ltd). To reduce the need to service devices, hydrophones could be cabled directly into existing infrastructure, or cabled back to land for systems close to shore. Although cabled systems may still need relatively frequent servicing and may be difficult to fix if they go wrong, they remove the need for voluminous onboard data storage and large batteries onboard and allow for continuous high frequency monitoring with no need for duty cycles. Consideration should be given early in MREI projects to including cabled hydrophone systems in the design, if at all practical.

Table 2 – Advantages & disadvantages of static PAM

Advantages	**Disadvantages**
Can provide a long time series of data	Duration of time series limited by sampling frequency, duty cycle, memory size and battery power
Relatively unaffected by weather conditions and can collect data at night unlike visual survey methods	Only provides a minimum assessment of presence of animals (as dependent on animals vocalising) and most systems cannot be used to estimate absolute densities of animals.
	Difficult to distinguish among species (other than harbour porpoises vs dolphins)
	Detections reduced in noisy environments (such as highly tidal environments)
	Clicks only detectable within a few hundred metres and when directed towards the hydrophone (since echolocation beams are highly directional)
	Spatial coverage of a single device is limited, so may require arrays to collect data at a suitable spatial scale
	Dependent on propagation which varies with depth, sediment type, sea temperature & other oceanographic variables
Relatively cheap (dependent on device, mooring type and frequency of visits to download data)	Devices can be lost due to weather, trawling, and/or failure, requiring redundancy to be built into any design
One of the few methods able to produce enough data to provide the *power to detect change* in cetacean behaviour as a result of MREIs	Can be confounded by behaviour if animals use sounds differently depending on activity (e.g. using more at night, during foraging, etc.)

Emergent Technologies

There are technologies on the near horizon that will allow for more sophisticated processing, storage and data retrieval. These devices will allow for on-board live processing of data to identify and classify both whistles and clicks (or other sound types) automatically using software such as the open source PAMGUARD. Data can be sent back in real time or at programmed reporting times via cable (e.g. attached directly to the MREI infrastructure and cable data directly back to base) or wireless (e.g. via mobile phone, wi-fi, or satellite networks). Longer deployment times can be achieved by using cabled systems or solar power. Such systems could allow for real time mitigation, giving an operator real time information about cetacean presence.

Other developments include drifting vertical arrays of hydrophones to plot fine scale 3D movements of vocalising animals (Wilson et al. 2013a). One application is to determine the proportion of time animals spend at different depths for assessing collision risk pre-construction (Macaulay et al. in prep). Also arrays of hydrophones placed on structures (e.g. in an array placed physically on e.g. a tidal turbine) can be used to examine movement patterns in 3D around the turbine itself to assess collision risk in the post-construction phase (Marine Scotland, 2014). However, if these devices are fixed to tidal turbine structures they may still have to contend with high tidal flow. Integrating hydrophone monitoring systems within the MREI infrastructure also has the benefit of providing a potential real time mitigation tool, allowing for continuous monitoring and reducing the boat costs involved in recovering devices to download data and replace batteries.

Acoustic monitoring considerations

Acoustic devices can vary in their sensitivity, and so one device may detect more vocalisations than another (Kyhn et al. 2008; Verfuβ et al. 2010; Dahne et al. 2013), although perfect detection cannot be expected from any device. Calibration may therefore be necessary to allow for detection rates to be compared between devices. However, the ability to detect vocalisations has been shown to be dependent on a range of factors (Verfuβ et al. 2010). Detectability can vary with depth, whether due to animals spending more time at different depths or due to oceanographic conditions (such as thermoclines) that change propagation patterns, and whether animals are facing towards the hydrophone (since echolocation clicks are highly directional). Ambient noise can also vary significantly dependent on mooring depth, with noise due to waves and bubbles close to the surface, and noise produced by moving sediment close to the bottom. To account for differing detection rates due to environmental noise, noise levels should ideally be recorded alongside cetacean detection (e.g. additional sound recorders together with click detectors) (Verfuβ et al. 2010). Time periods where noise levels are too high to differentiate cetacean vocalisations from background noise should be excluded (Diederichs et al. 2008). Accounting for ambient noise variability is extremely important in high-energy sites such as tidal streams, as noise intensities have been shown to vary considerably across small spatial scales over the course of individual tidal cycles at such sites (Carter 2013; Wilson et al. 2013a). This can have a significant impact on devices' abilities to detect vocalising cetaceans at particular times and places. As a result, devices' detection ranges are likely to expand and contract to an unknown extent, complicating efforts to assess cetaceans' usage of these sites.

The following parameters are recommended for use in static PAM studies, especially in relation to click detectors (Verfuβ et al. 2010):

- Percent of detection positive time units per monitoring time unit.
- Waiting time
- Encounter duration

Percent detection positive time units per monitoring time unit. The length of time unit should be chosen carefully to consider: (i) temporal autocorrelation – need to ensure independence between time units (e.g. Detection Positive Hours (DPH) has been shown to have minimal temporal autocorrelation (Brookes et al. 2013)); (ii) the animal density in the study area to obtain around 30% positive time intervals (as suggested by Tregenza & Pierpoint 2007), and (iii) the overall aim of the study (e.g. whether studying long term or short term effects).

Waiting time is the length of time between click trains of cetacean vocalisations – this can be used to assess impact of impulsive events such as pile driving when compared against a control distribution of waiting times from randomly assigned points in time (e.g. Thompson et al. 2010).

Encounter duration gives an indication of the amount of time animals spend in the vicinity of the recording device (Diederichs et al. 2008). However, it can be difficult to define due to the difficulty in defining an ‘encounter’, oft quoted is the figure of 10 minutes: if there is <10 minutes between click trains then it is considered a single encounter (e.g. Brandt et al. 2011).

Study Design

SMRU (2010) in their advice to the Crown Estate on monitoring methodology for marine mammals around MREIs, recommended static acoustic monitoring as a principal technique for characterising seasonal baseline acoustic activity, and it is considered the most cost effective way for monitoring impacts at all MREIs. Thompson et al. (2014) in their advice to Marine Scotland also recommended long term static PAM for both characterisation and post-consent monitoring. Long-term monitoring using both techniques is also underway at the Wave Hub (Witt et al. 2012).

Design of monitoring methodologies for static PAM of dolphins and porpoises around MREIs will be different dependent on the type of MREI (e.g. wave, wind or tidal) and monitoring stage (pre-consent monitoring or impact monitoring). Wave and wind MREIs will be considered separately from tidal MREIs due to the different challenges posed by working in high tidal current environments. Characterisation survey design is likely to differ from monitoring survey design. Characterisation (baseline) surveys should also provide data that will permit the robust design of any subsequent impact studies that may be required at those sites.

In all designs redundancy should be factored into the design, either by doubling up on devices per mooring or increasing the numbers of moorings. Devices can also shadow each other on doubled up deployments. Where mooring loss through trawling or exposure to extreme sea conditions is a primary concern, it is better to deploy more moorings with single devices than to risk losing moorings with several devices attached. Thompson et al. (2014) calculated a 10-20% device loss rate through extreme sea conditions and trawling activity, however loss rates have been reported as high as 80% in the Baltic Sea. High loss rates due to weather or ship strikes could be reduced through mooring modifications such as the use of acoustic release devices over surface moorings, although device failure can also be quite high with such devices. Secondary mooring recovery options, including controlled grappling from a vessel and ROV-assisted search and recovery, should also be considered. Any design of an acoustic array requires consideration of environmental features such as water depth, seabed substrate, tidal conditions, and distribution of potential hazards such as fishing areas, shipping lanes and wreck sites. Deployment on or near to wreck sites can help to reduce trawling losses. It should be noted that ecological census techniques typically survey perpendicular to environmental gradients.

Wave and wind MREIs

The main concerns with wind farms tend to be associated with disturbance due to pile driving during construction (Carstensen et al. 2006, Thompson et al. 2010, Brandt et al. 2011, Teilmann & Carstensen 2012). This may also be a concern for some types of wave energy or tidal devices, if they are using similar installation methods, such as pile driving. Overall increase in noise is considered a concern, whether during construction due to increased boat traffic and construction noise or during operation. Noise levels should be assessed with respect to background levels and to what distance they cause behavioural disturbance (e.g. Bailey et al. 2010). Whatever the specific concern of the wave or wind energy development, any monitoring program should be designed to address the specific concerns of the site, species, and device type. It should also be noted that there is an increasing push to develop floating wind turbines (e.g. Jonkman & Matha 2011) which are likely to more closely resemble wave energy devices in terms of their overall impacts.

Characterisation

For characterisation surveys it may be sufficient to deploy only a few devices to assess (i) whether vocalising cetaceans are present within the MREI footprint; and (ii) temporal variability (at tidal, diurnal or seasonal scales) in occurrence of cetaceans within this area. The number of PAM devices and array design will depend on factors such as habitat, potential MREI footprint area, device type, and likely presence of EPS or SAC protected populations. Characterisation surveys can provide data about the importance of the site for cetaceans (both in likelihood of occurrence and frequency of occurrence), and information on temporal variability can help in the design of an installation programme (especially when using pile driving) to avoid peak times for cetaceans.

In small MREI sites, two separately moored PAM devices may be sufficient to gather characterisation data on occurrence of cetaceans and seasonal trends (single devices are not recommended due to potential for failure and loss). However, there can be very large differences in occurrence over relatively small scales (e.g. O'Brien et al. 2012), so multiple devices and/or multiple monitoring locations should be considered even at small sites (including redundancy against failure).

Post-consent monitoring

Post-consent monitoring should be designed to address the uncertainties within the EIA, so design will be very dependent on a multitude of factors including presence of protected species, habitat type, device type and installation method (e.g. pile driving is considered to have the highest risk of negative impact on cetaceans). However, to detect impact a BACI (Before-After-Control-Impact) or IG (Impact Gradient) design will be required.

A *BACI* design requires very careful selection of ‘control’ sites, which are assumed to be independent of the impact site but as similar in habitat type as possible. This assumes that control sites fall outside the zone of impact, which can be very large (e.g. acoustic disturbance (>20 km for pile driving, Brandt et al. 2011)). In practice this is difficult to achieve due to problems with identifying suitable control sites especially for mobile marine species that move between sites often resulting in sites being non-independent (e.g. Thompson et al. 2010). One control site is insufficient for evaluating impact, so multiple control sites are recommended (Underwood 1991, 1994). The number of control or reference sites required to detect impact using a BACI approach is dependent on the sensitivity required. Another option is to include several static PAM locations per control site, for example, in the Moray Firth it was found that at least 8 CPODs were required in both the control and impact site to detect a difference between the two sites (Thompson et al. 2014).

An *IG* design assumes that there is a decreasing risk of impact with distance from the impact, and involves monitoring at multiple sites at increasing distances from the development before and after impact (Ellis & Schneider 1997). This method is considered more appropriate for monitoring impacts of MREIs on mobile marine species such as cetaceans (Thompson et al. 2010, Trendell et al. 2011). It requires an understanding of the spatial and temporal scale of any impacts for designing the layout of the graduated array of devices. For example, when considering the impact of pile driving, monitoring may be required well beyond the footprint of the development, since porpoises have been shown to be disturbed to distances of greater than 20 km from the sound source (Brandt et al. 2011). PAM devices should not be set along environmental gradients (e.g. depth) that could confound the impact assessment. Designs should comprise of multiple transects radiating out from the impact area (ideally at least 4 perpendicular to each other), with the starting direction selected randomly. IG methodology allows for the statistical evaluation of both the magnitude and spatial extent of impact, and has already been used to assess magnitude and extent of impact of developments on cetaceans (Brandt et al. 2011, Thompson et al. 2013, Thompson et al. 2014).

To adequately design either a BACI or IG survey programme, some knowledge of the frequency of occurrence of animals at the site and any control sites should be gathered in advance. This can be achieved with appropriate forward planning at the characterisation phase or soon after consent is received. There should at least be sufficient monitoring within the season of interest to highlight issues in the monitoring design early on, and allow for an assessment of the survey design's statistical **power to detect impact**. This could be backed up by year-round monitoring to gain an understanding of short-term temporal variation in animal occurrence.

At sites where the baseline levels of activity are low, it should be acknowledged that it is unlikely that an impact could be detected even with much increased effort. Where baseline levels of activity are higher, changes of a few hours of detection per day should be detectable if they exist and enough sampling effort is used. Thompson et al. (2014) subsampled data to determine the fewest sites that would still lead to the model being selected on the basis of AIC. This was around eight devices per site (with a recommendation of 10 to mitigate against device failure or loss) in an area where baseline detections were of the order of around 10 hours per day. Such criteria are useful to begin to understand the magnitude of effort required, but decisions for each site should be made in collaboration with the regulator and their advisors to account for differences in detection and the objectives of the study.

Although the ultimate aim of impact monitoring is to determine whether this is an impact to the population, this requires a large amount ancillary data such as population status and trend, number of impacted individuals and the level at which they are impacted, and the consequence to the individuals of being impacted. Acoustic monitoring is able to answer questions about whether animals are distributed, and the spatial and temporal scale of that disturbance, which can contribute to this process, but cannot answer the question about population consequences alone. Also, acoustics on its own may not be sufficient to define "impact". If animals behave differently (e.g. stop echolocating) during an impact, then acoustics would tell us they were absent, when that might not be the case. Though, there is some evidence that this may not be an issue, at least for porpoises, since a study carried out by Thompson et al (2013) found the same pattern in porpoise behaviour to seismic surveys from both CPOD and digital aerial surveys, with fewer porpoises closer to the seismic vessel.

Post-impact monitoring should continue as long as required to assess the assumptions of the EIA, but should be sufficiently long to assess how long it takes cetaceans to return to baseline levels (e.g. harbour porpoise detections returned to baseline levels within hours to days after being exposed to seismic activity in the Moray Firth (Thompson et al. 2013)). However, it should be noted that long-term trends may be difficult to detect at all, given the species' longevity, low reproductive rate and large home ranges.

Thus recommendations include:

- IG design is recommended where practical for monitoring impacts on cetaceans
- IG should consider the spatial *scale* of impact, and should not be carried out along gradients that could confound measures of impact.
- BACI designs should include sufficient control(s) and replication within sites to have confidence in the design's power to meet the monitoring objectives.
- 1 year of baseline should be collected to inform the design of any impact studies and ensure that these have sufficient statistical power to detect change.
- Post-impact monitoring should continue as long as required to assess the assumptions of the EIA, but should be long enough to measure return to baseline levels.

Tidal stream MREIs

The highest risk to marine mammals from tidal stream devices is considered to be collision risk, although barrier effects may also be a concern, especially where devices are placed within narrow channels. Therefore any monitoring should attempt to address issues such as assessing the magnitude of response to the turbine, i.e. whether animals collide, move around the device, or avoid the area altogether such that the turbine forms a barrier to movement.

Monitoring in high tidal environments places very different challenges on 'static' acoustic monitoring of dolphins and porpoises. Mooring devices in areas of very high tidal current needs to be carefully considered due to the challenges of deploying and retrieving devices, ensuring devices remain in position and out of high ambient noise levels (Wilson et al. 2013a). Fixed autonomous acoustic recorders require robust moorings to resist the current, which adds to mooring weight, complexity and cost. More complex moorings may potentially require larger vessels to safely deploy and retrieve them, raising further issues of cost, manoeuvrability and vessel availability (Dudzinski et al. 2011). Furthermore, mooring deployment and retrieval may only be possible during brief periods of slack water, making logistics of operating in short weather windows even more challenging. Many standard moorings include some kind of surface marker (e.g. buoy or float) to allow them to be located and recovered more easily. Strong currents in tidal streams may, however, push entire mooring lines (including buoys) towards the substrate, pulling the surface marker under water and generally increasing the risk of mooring lines becoming fouled or snagged on the sea bed. Under these conditions, damage or loss of either PAM devices or the entire mooring is a genuine risk. Rapid movements or changes in orientation may also interfere with devices' ability to record marine mammals. Tidal streams also produce elevated levels of ambient sounds which can mask marine mammal sounds to varying degrees, particularly during peak tidal flow, due to a combination of moving sediment, wave action and bubble formation. Finally, the rapid flow of water past the hydrophones in the detectors adds self-noise to the data, interfering with marine mammal detection (Au & Hastings 2008, Bassett et al. 2010). Different approaches to mooring in energetic sites are discussed in greater detail below.

A novel monitoring approach combines static PAM within calm water close to the tidal channel (where available) with drifting PAM which can be deployed within the areas of high tidal current (Wilson et al. 2013a). Drifting PAM is carried out through attachment of PAM devices to surface drifters or buoys which are set adrift in tidal streams. The devices can be either click detectors such as C-PODs (Wilson et al., 2013a) or acoustic recorders (Carter 2013). Allowing detectors to drift passively with the water has several advantages: (1) Detectors no longer run the risk of being damaged or lost by snagging the seabed, (2) the problem of self-noise is resolved because the detectors are now effectively stationary relative to the (moving) water around them, (3) detectors can sample a far larger area than when moored and (4) can be repeatedly redeployed as needed to create a dynamic picture of marine mammal presence in tidal streams over time (Wilson et al. 2013a). Potential disadvantages include less predictable coverage of particular areas, the need to retain a safety vessel on standby for recovery and redeployment, and methodological difficulties in analysing the data (Wilson et al. 2013a). If multiple devices are set adrift at different locations and different phases of the tidal cycle (including the spring-neap cycle), it is possible both to describe dolphin and porpoise use of the area and the ‘soundscape’. The disadvantage of such systems is that they achieve less extensive temporal coverage, but combined with continuous monitoring at nearby sites in calmer water adjacent to the tidal stream, they can validate the findings of the statically moored devices. Drifting PAM also allows for noise characterisation of the tidal environment, highlighting areas where noise levels are highest at peak flow and thus pinpointing locations that may be less favourable for long-term monitoring using moored devices. They therefore provide a useful new tool that may be used alongside or instead of traditional methods to investigate aspects of tidal-stream site use by odontocetes.

Monitoring marine mammals in such environments is still in its infancy (Keenan et al. 2011, Wilson et al. 2013a), so monitoring methods are likely to develop over time. At Strangford Lough, the static monitoring design comprised 10 C-PODs placed both within the channel and outside to allow for an assessment of movement of harbour porpoises between the inner and outer Lough & through the channel (Keenan et al. 2011).

Characterisation

Site characterisation for tidal sites is required to answer similar questions as to wind and wave devices – characterisation surveys should be able to assess species diversity present in the area, their temporal and spatial distribution, and patterns of usage of the area. This will usually require several moored devices to assess temporal variability in usage of the tidal area, and a series of drifting PAM deployments to assess small-scale movements of animals in the stream in order to assess risk of collision.

Post-consent monitoring

As with wave and wind devices, there should be sufficient baseline data to ensure the monitoring design has the power to detect change. Survey designs tend to be IG rather than BACI due to the difficulty in selecting suitable reference sites.

Monitoring designs are likely to be considerably different in high tidal flow areas in narrow channels than in large areas of tidal flow such as the Pentland Firth. Given their comparatively limited (and variable) detection ranges, solitary moored static PAM devices may not provide sufficient detail of animals' habitat usage outside the immediate area of interest. If more details are required on spatiotemporal variability in animal distribution in a wider area around the site, multiple moored detectors are needed, typically arranged in a grid or line pattern at intervals ranging between hundreds of metres to kilometres (e.g. Gallus et al. 2012). Current evidence suggests that small cetaceans such as harbour porpoise tend to periodically aggregate outside tidal channels in tidal jets and eddy fields (Wilson et al. 2013a, 2013b). This implies that monitoring a single site in the middle of a tidal channel would fail to detect any changes in porpoise distribution as a result of declining turbulence due to the MREI's energy outtake. Potential deployment configurations include moored devices within tidal channels, on either side of channels as well as some distance beyond the boundaries of channels, in an attempt to assess directions of movement through channels and potential barrier effects. Larger offshore areas may require multiple units spread across a wider area, taking into account seabed topography and ease of access. Moored static PAM devices may provide detailed information on daily (ebb-flood) and monthly (spring-neap) tidal cycles. Logistical considerations such as those outlined in the previous section may, however, preclude more complex arrangements in energetic sites.

To date up to four drifting PAM devices have been deployed at once in a tidal stream site without undue difficulty (Wilson et al. 2013a). Deployment duration has increased as the drifting PAM designs have improved, but currently remains on the order of hours to days (S. Benjamins, SAMS, unpublished data). Drifting PAM can be deployed in large numbers or redeployed repeatedly to achieve high-intensity coverage of narrow tidal channels, or can be set adrift in more open-water sites for longer periods of time. When working in comparatively small sites, drifting PAM could be deployed upstream at regular intervals (e.g. once every 30 minutes) to assess how spatial distributions of detections changed in response to the tidal cycle. Larger sites might require multiple devices deployed across a larger area to achieve better coverage. Under these conditions, communication with drifting PAM systems becomes crucial if they are not to be lost. Efforts are currently underway to improve drifter recovery rates to allow deployments over several days at a time (S.

Benjamins, SAMS, unpublished data). Investigating longer-term (e.g. seasonal) trends would require repeat deployments of drifting PAM over extended periods.

Deployment & retrieval

Deployment and retrieval of devices can be challenging, especially in offshore environments that are prone to poor sea conditions, and in high tidal current environments.

Mooring

There are two main ways to deploy devices: moorings with surface floats, and acoustic release moorings with no surface signature (Table 3).

Table 3 – advantages and disadvantages of surface buoy moored and acoustic release systems

	Advantages	Disadvantages
Surface buoy moorings	Cheaper Can be easier to retrieve	Suffer from wear and tear due to action of waves, tide and salt. Conflict with fishermen (more likely to get trawled and lost) Ballast for deep water deployments has to be very heavy so difficult to deploy Noisy
Acoustic release	Devices less likely to get lost Smaller and lighter Reduced noise from drag of mooring components.	More expensive More prone to risk from trawling May fail to release, or release earlier than intended

There are a number of options for anchoring surface-buoy moorings (e.g. see Dudzinski et al. 2011), the most frequently used are the 1 or 2 anchor systems. Dual anchor systems allow for easier swap over of devices; however single anchor systems are often preferred by fishermen since they occupy a smaller volume of water. Acoustic releases have many advantages over surface-buoy moorings; however acoustic releases can fail, so where data are critical, dual acoustic release systems would provide a measure of redundancy. Acoustic releases are the recommended option for mooring devices in high tidal currents, though consideration should be given to factors such as sediment type (e.g. acoustic devices getting covered in sand in a tidal channel & thus not able to be retrieved). It should be noted, however, that acoustic release systems can be significantly more expensive than the acoustic device itself, so there may be a trade-off between the cost of mooring and value of the data, and some cases, it may more cost effective to deploy subsurface moorings with no release, and recover them by using an ROV to attach a hauling line to the surface.

An alternative deployment method would be to attach devices to existing infrastructure, therefore incorporating devices into the design of MREIs – this may also allow for cabled power and data so saving on costs of deploying and retrieving devices to download data. This may also be the only option for acoustic monitoring in very shallow waters such as for the Oyster wave energy device where mooring devices would prove impractical. Previous studies have used oil and gas platforms as deployment structures (Todd et al, 2009) as well as navigation buoys (Wilson pers comm).

Should retrieval methods fail (surface buoy marker lost, or acoustic release malfunction) other retrieval options include the use of ROV, divers or grappling (see Chelonia Ltd).

Licensing

Deployment of devices on the seabed (or releasing devices for drift) may require a number of permissions before devices can be deployed, and may require a Marine Licence. Organisations that should be consulted include:

- Crown Estates – for permission to deploy devices on the seabed & fee for deployment
- Local fishermen
- Local harbour authorities
- Boat clubs and other organisations with marine interests

In Scotland, Marine Licence approval can take 6-8 weeks for scientific instrument deployment (see http://www.scotland.gov.uk/Topics/marine/Licensing/marine/Applications) and the locations will be consulted upon with agencies concerned with safety of navigation (e.g. MCA, relevant port authorities and lighthouse board), as well as other users of the sea (e.g. local fisheries organisations). A 'notice to mariners' must be issued detailing the position of all licensed moorings to Marine Scotland, the Northern Lighthouse Board, UK Hydrographic Office, port authorities, Maritime and Coast Guard Agency, harbour masters and any other people who may be working in the area. The notice should also be published in fishing publications such as the Kingfisher Bulletin.

Health and safety

Considerations should be given to all aspects of deployment with respect to health and safety, and appropriate risk assessments carried out. For example, if lithium batteries are used in devices, care should be taken due to explosion risk if they come into contact with water. Particular attention should be given to ensuring that any mooring lifting or deployment that is required is undertaken in suitable sea conditions, with appropriate lifting equipment and using crew with sufficient experience.

Since moorings can be large and heavy, Maritime and Coastal Agency (MCA) certified vessels should be used for deploying moorings and the associated devices, and careful consideration should be given to health and safety issues of deploying such large devices.

If external operators (consultants, academic institutions, etc.) are to undertake the monitoring, it is important to integrate their activities into the site operator's health and safety protocols as early as possible to prevent administrative delays.

Other considerations

Consistency of methods over time

For long projects it is likely that acoustic devices used for monitoring cetaceans will improve and new devices will emerge. Where possible the same devices should be used for the whole duration of the project. Where new devices are introduced they should be cross-validated with previous devices used on the project by placing both devices in the same location for a deployment period and comparing results between versions or devices.

Data storage

One aspect that should be given careful thought is with respect to data storage and archiving. In particular, sound recording devices generate a much larger quantity of data than click detectors. All data should be carefully and clearly catalogued and archived appropriately as data may need to be retained for long periods of time to allow for assessment of cumulative impacts. Two copies should be retained in different locations for redundancy should one copy be lost or destroyed.

Data access

There is a need for improved knowledge of marine ecosystems at all levels. Many organisations and agencies collect various kinds of marine data in the course of their activities. Such data are expensive to obtain and may have wider relevance beyond the purposes for which they were collected originally. There is therefore a strong incentive to share marine data as appropriate with other interested parties (taking into account commercial sensitivities and intellectual property rights). In the UK, the Marine Environmental Data and Information Network (MEDIN) promotes sharing of, and improved access to, these data however this only covers the metadata for sound recordings rather than the data itself (MEDIN 2013). Developers should be encouraged to allow sharing of data through such networks, to improve understanding of marine mammal distribution in UK waters.

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