# Methods for tracking fine scale underwater movements of marine mammals around marine tidal devices

marine scotland

# Marine Mammal Scientific Support Research Programme MMSS/001/11

## Task MR3:
## Methods for tracking fine scale underwater movements of marine mammals around marine tidal devices

Sea Mammal Research Unit

Report to
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## Contents

# 1 Executive Summary

1. The Scottish Government has the duty to ensure that the development of offshore renewable sectors is achieved in a sustainable manner in the seas around Scotland. There is a need to evaluate potential interactions between offshore renewables and marine wildlife as a matter of priority. One such potential interaction is the effect of underwater turbine generators on marine mammals. This report considers the possible technological methods for tracking fine scale underwater movements of marine mammals around marine tidal devices. Since this is a dynamic field the Report will be updated annually.

2. We define the target specification for interaction data as follows: a range of 100m of the turbine which have a temporal resolution of 1s and a spatial precision of 1m.

3. These data requirements place a heavy demand on existing technology. However, we identify three generic methodologies that show potential:

- Animal-borne telemetry devices (tags),
- Passive sonar arrays to track animals that vocalise or that carry acoustic pingers, and
- Active sonar systems, the underwater equivalent of radar.

4. Animal-borne telemetry devices. These electronic 'tags' are attached to locally captured animals (acoustic pinger tags are discussed below). Capturing cetacea is not currently feasible and so this technique is limited to seals. The difficulty in recapturing individual tagged UK grey and harbours seals (within the six month attachment period) means that those type of tag which rely on retrieval for downloading data are not an option. The best option is a tag that relays surface GPS locations and detailed dive depth profiles through the mobile phone system (the GPS/GSM tag). GSM coverage is sufficient for most tidal devices areas. It is technically possible to incorporate dead reckoning (DR) so that the 3-D underwater track can be accurately generated in between surface GPS locations. The drawback is that water current data are required for this calculation at a level of detail that is not currently feasible.

5. Passive acoustic detection (PAM). PAM is essentially an array of hydrophones that can detect (to species level) and track vocalising animals (primarily toothed whales – especially porpoises and dolphins). A static array of hydrophones around a turbine should be capable of achieving the required level of precision. It is an unsatisfactory system for baleen whales that vocalise unpredictably. Whilst seals also do not regularly vocalise, they could be captured and fitted with individually coded acoustic 'pinger' tags. They would thus be capable of being tracked by a PAM system.

6. Active Sonar. Active sonar is akin to underwater acoustic radar. It has been proven to detect and track marine mammals in the vicinity of underwater turbines at

sufficient spatial and temporal scales. It is good at detecting both seals and cetacea and viewing the raw data usually allows distinction between a seal and an odontocete. However we recommend that active sonar is used in conjunction with a PAM system, whereby the species (or individual, if acoustically tagged seals are used) discrimination is greatly improved. Active sonar is the only technology that will detect and track baleen whales.

7. To balance the strengths and weakness of the above technologies we suggest that the following generic configuration represents the best probability of achieving the overall objective:

- Establish a static PAM array around one or more turbine to track vocalising odontocetes.
- Tag local seals (c. 20+) with acoustic pingers so that they can also be detected and tracked by the PAM array.
- Establish one or more active sonars on the turbine to detect and track all marine mammal species (including baleen whales). Generic discussions with engineers indicate that such an approach is feasible. However site-specific discussions have yet to take place.

8. Detection of a turbine blade actually striking a marine mammal is essential to interpret the consequences of fine scale movement. However none of the tracking technologies is likely to provide data sufficient to confidently discriminate an actual marine mammal strike from a near miss. Although high risk, we suggest that the feasibility of two possible approaches be explored. First, the physical detection of a strike using stress sensors built into the turbine blades. Second, the development of an underwater video surveillance system.

9. In Appendix II we illustrate our technological approach with a case study scenario at the proposed Sound of Islay turbine array.

# 2 Introduction

The Scottish Government has a target for 100% of Scottish demand for electricity to be met from renewables by 2020 creating a balanced portfolio of both onshore and offshore technologies. Offshore renewables have the potential to make a significant contribution to Scottish Government targets for delivery of renewable energy generation. The Scottish Government has the duty to ensure that the development of offshore renewable sectors is achieved in a sustainable manner in the seas around Scotland.

Strategic Environmental Assessments (SEA) on offshore renewable development has identified a need to evaluate potential interactions between offshore renewables and marine wildlife as a matter of priority so that appropriate mitigation can be investigated and applied. One concern with respect to the impact of tidal turbines on marine mammals is the potential for mortality or injury through collision with rotating turbines and the ability for marine mammals to take avoiding action (Wilson *et al.* 2007a). To evaluate the risk of such collisions means understanding the fine scale underwater movement of these mammals within the immediate vicinity of tidal turbines.

Existing technologies for tracking underwater movements are diverse and include satellite/GPS telemetry, passive acoustic monitoring, active sonar and video techniques. Telemetry devices have long been deployed on seals to answer a range of research questions, including how seals use the marine environment, foraging patterns, diving behaviour and temporal/spatial distribution. They have the potential to provide good spatial coverage but are restricted in terms of tracking fine scale underwater movements and, their reliance on being able to predict the movement patterns of individual animals which may rarely enter the areas of interest. Active and passive sonar have been actively employed in areas of tidal development (e.g., Ramsay Sound, European Marine Energy Centre (EMEC), Strangford Lough), and when placed within the vicinity of the tidal devices may offer a more appropriate method for direct observations of potential collisions. Video can provide data on movements but may be restricted by limitations on underwater visibility due to local conditions (e.g., turbidity, light constraints, biofouling).

The aim of this project is to review current and developing technologies for tracking the fine scale underwater movements of marine mammals in high energy tidal sites, and to predict the feasibility of these technologies for direct observation of potential collisions. Possible development of new technologies should also be investigated where current devices may not be applicable.

### 2.1 Objectives

In response to this gap in knowledge, we have been tasked by Scottish Government to

a. review all current and near-future technology for tracking the fine scale underwater movement of marine mammals in the vicinity of a turbine

b. predict the feasibility of these technologies for direct observation of movements and possible collision in high energy tidal stream environments

Our precise remit is provided in Appendix I. The technologies we describe here are continuously being developed and so this document will be reviewed on an annual basis.

In Appendix II we provide, as a case study, a scenario to provide fine scale interaction data at the proposed Sound of Islay turbine array development. The information provided in the case study reflects the position at the time of this reports preparation.

## 3 Fine scale underwater movement

The objective is to detect and describe fine scale movements of marine mammals in the vicinity of an operating underwater turbine. We thus have to consider what is meant by 'fine scale'. The questions underlying the main objective are to investigate if and when an animal becomes aware of proximity to a turbine, what its reaction is, and whether the encounter results in a collision. There is no direct way of determining awareness. We can however detect change in movement behaviour. But there is no simple mapping between awareness and behaviour. Behaviour change may be the result of other stimuli. Similarly, awareness of the proximity of a turbine may not invoke behavioural change if the individual does not perceive risk.

Whilst acknowledging the imperfect nature of inferences that can made from movement behaviour, we must propose a target precision and range for the required data. We therefore propose that:

- the range of measurement should be within 100m of a turbine,
- temporal resolution 1s
- spatial precision 1m

This target is a yardstick to assess technological candidates. It may well be that none achieve this target, and thus the iterative process of matching technology to biological questions may lower the target.

It is likely that even detailed tracks may fail to distinguish between an impact and a near miss. Impact detection methods are thus discussed in Section 5.

## 3.1 Candidate Technologies

There is a diverse set of telemetry (McConnell *et al.* 2010) and detection (Hastie 2012) techniques that are available to study marine mammal movements and behaviour, which the authors have considered extensively. However the data requirements of our objective to record fine scale interaction places a heavy demand on existing technology. However, we identify three generic methodologies that show potential:

1. Animal-borne telemetry devices,
2. Passive sonar arrays to track animals that vocalise or that carry acoustic pingers, and
3. Active sonar systems.

Each is discussed in turn below. In Table 1 we provide an overview of their attributes for comparison. An explanation of these attributes follows:

- **Identify to species**. Can the technique discriminate to species level?
- **Identify to individual.** Can the technique reliably identify the individual involved?
- **Precision**. What is the expected spatial and temporal precision that can be expected? Note that a system (e.g. dead reckoning) can have good precision relative to previous locations, but poor absolute precision in our ability to place the track in real space (e.g. latitude and, longitude coordinates).
- **Plausible sample size**. This describes the likely power of the observation technique – in other words the number of 'close interactions' we might expect to document. This is primarily a function of local animal density and duration of study. For techniques that involve the capture and tagging of individuals it is, more precisely, a function of the local density of *tagged* individuals. In turn, this is a function of both the numbers and movements of locally tagged animals.
- **Data Latency**. This is the delay in getting the data processed to a level where detections can be determined. Zero data latency would be *real time* data relay and processing.
- **Range.** This is the distance from the device within which an animal can be detected and tracked.
- **Taxa suitability**. The applicability of each method to different taxa of marine mammals.

The values in Table 1 are for illustrative purposes. The real values depend upon the location of the study and the density of marine mammals found there. For the most, part they can only be refined with pilot/experimental studies. As we mention in the Introduction, the aim is to focus discussion on the parameters that are operationally significant, rather than making definitive predictions.

## 3.2 Animal-borne telemetry

In this section we investigate the use of active electronic tags that can be applied to captured marine mammals[1]. This approach permits the detailed longitudinal study (up to about six months) of the tagged individuals. However there is a risk when there is a single geographical focus interest such as a turbine array. Marine mammals are wide ranging and thus those tagged close to such a focal point may subsequently emigrate. Thus we need to know *a priori* the target species' movement patterns, and thus the required sample size to achieve the statistical power to capture interactions at a focal point.

Note that the catching and tagging of seals in the UK, whilst requiring a high level of expertise and permitting[2], are now reasonably routine procedures. This expertise does not currently exist in the UK for small cetacea, although by-caught porpoises are regularly *tagged* off Denmark (Geertsen et al. 2004). Thus we exclude cetacea from this technology.

It is logistically difficult to recapture specific, instrumented grey and harbour seals. Whilst an automatically-timed or remotely triggered tag release mechanism is a possibility, it is usually logistically difficult and costly to recover detached tags from animals that can roam far. This fact thus excludes tag types where detailed information is stored in memory for subsequent physical retrieval (e.g. time-depth recorders and the Animal Diary dead-reckoning tags (Wilson *et al.* 2007b)). We thus limit our discussion to those tag technologies that relay data ashore. Existing seal tag designs can relay data ashore by either Argos satellites, or the GSM (mobile phone system). Whilst there are other radio systems potentially available, none combines the required small size, efficiency and rapid start up (to accommodate short surfacing periods)[3].

### 3.2.1 Argos satellite tags

Historically (and currently for many marine mammal species) the Argos satellite system (Argos 2008) has provided both a means to relay data and to estimate approximate locations. Its primary advantage is its global coverage and that data (including stored behavioural information) can be sent immediately on an animal surfacing. For these reasons, it has been used to track seals (McConnell *et al.* 1999), large whales (Mate, Mesecar & Lagerquist 2007), and small odontocetes (Sveegaard *et al.* 2011). However, the location information it provides are sparse (perhaps one to six locations per day) and of low precision (errors of more than 1 km are common – see Vincent *et al*. (2002)). Argos-based telemetry data are therefore of insufficient quantity or quality for investigating fine scale movements around marine renewable devices.

[1] Active acoustic tags are discussed in the Passive Acoustic Monitoring - Section 3.3.
[2] These procedures require an appropriate Animals (Scientific Procedures) Act 1986 license.
[3] The Iridium satellite system (http://www.iridium.com/default.aspx) may have the potential to become a candidate data relay system. However its practical application in marine mammal telemetry has yet to be demonstrated.

### 3.2.2 GPS/GSM tags

#### 3.2.2.1 GPS

The use of the Global Positioning System (GPS) is an option for increasing location accuracy. However, the brevity of surfacing intervals (effectively shortened even further by periods of wave wash over the GPS antenna) is generally shorter than the time required to calculate a fix from a cold start (time to first fix from cold). This issue was resolved by the Fastloc innovation. Fastloc (Costa *et al.* 2010) which obtains a snapshot (< 0.2 s) of GPS satellite transmission when the animal surfaces. This is then processed and condensed into about 32 bytes of pseudo-range data which are time-stamped and stored for subsequent transmission. Once these data are received ashore, the pseudo-range data are post-processed to provide a series of accurate GPS fixes. Fastloc data can be relayed within Argos uplinks (transmissions that are successfully received and relayed by the satellite segment), but this imposes severe restrictions on the amount of GPS fixes that can be relayed. Lonergan *et al*. (2009) emphasised that accurate track recreation depends not just on fix precision, but also on the number of fixes per day.

#### 3.2.2.2 GSM Mobile phone technology

GSM mobile (cell) phone technology is one solution to the Argos data bottleneck. Since 2004 tags developed by the Sea Mammal Research Unit (SMRU)[4] deployed on seals have used the mobile (cell) phone network to relay data ashore. In these GPS/GSM tags, data (including stored Fastloc and depth data) are collected routinely over periods of six months or more. Every time a seal swims within suitable GSM network coverage the stored data are sent ashore using GSM 2.5G link[5]. This allows high data rates to be achieved – and at low energy and financial cost. In their usual configuration the tags store data for up to two days before attempting to relay them ashore due to the energy overhead associated with establishing each GPRS session. However data latency could be potentially reduced to less than one hour if the site of potential interactions was within GSM coverage and software parameters were changed. However there is still a chance that the animal may not spend sufficient time at the surface (20 s uninterrupted) for successful GSM registration until it next hauls out. The short surfacing periods of cetaceans prohibits the use of GSM data relay.

GPS/GSM tags also record and relay detailed depth profiles within each dive. However these profiles are time based. An attempt to geo-reference them relies upon a linear interpolation between GPS fixes at the start and end of each dive. This introduces uncertainly into the track and thus to the locations at which to dive depths occurred. Since grey and harbour seals have dive durations in the order of 3- 5 minutes, this uncertainly may extend to many tens of meters. Thus we do not

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[4] http://www.smru.st-andrews.ac.uk/Instrumentation/Products/ Currently SMRU Instrumentation is the only provider of this type of tag functionality.

[5] The data are sent using a FTP protocol over a General Packet Radio Service (GPRS) link.

recommend standard GPS/GSM tags to determine fine scale interactions in seals or cetacea.

### 3.2.3 Dead reckoning

Dead reckoning (DR) uses data from on-animal movement (acceleration, attitude and speed through water) sensors to estimate the position of a tagged animal. In contrast to the other localization methods described above, DR is not a stand-alone method. It can be used to interpolate localizations and so improve the temporal resolution of infrequent positions, such as from surface GPS fixes, but DR cannot, by itself, give the geographic position of an animal. DR estimates the displacement of an animal from a starting position by integrating the velocity vector of the animal with respect to time. This requires regular measurements of the animal's velocity, i.e., its speed and direction. Both of these parameters can be estimated from sensors in a tag rigidly attached to the animal: the forward speed through water can be measured by a paddlewheel while the direction of movement, which is assumed to coincide with the longitudinal body axis, can be estimated from tri-axial accelerometers and magnetometers.

Although the idea behind DR is straightforward, there are two practical issues that complicate the picture. The first is the large amount of information that must be retrieved from a tag to recreate a track. Speed, direction and depth need to be sampled by a tag at least once per second to recreate a reliable track of an agile animal such as a seal. This means that about 500 bytes per minute (= 7 Mbytes per day) are collected by the tag, which is about 70 times the typical data relay rates of GPS/GSM tags in their standard configuration. Whilst we estimate that these tags could handle this elevated data relay rate, there would be a concomitant decrease in battery life.

The second issue is more serious and relates to the way that velocity is measured. The velocity over ground is required for geographic tracking but with respect to water the sensors in a candidate tag measure speed and direction with respect to the water. If the water current in the area is known, this can be added to the tag velocity measurement to estimate the velocity over ground. But any uncertainty in the total speed or direction will be integrated when computing the DR track leading to incremental positioning errors that grow with time (Shiomi *et al.* 2008; Shiomi *et al.* 2010). Errors can become substantial: a speed error of 1 m/s (2 knots) will result in a track error of up to 150 m in a 5 minute dive, assuming that GPS positions are taken at the start and end of the dive. It is important to note that not every attempt to obtain a GPS fix using Fastloc is successful and so only a proportion of dives will have start and end GPS location pairs. Thus, in areas with high currents such as those favoured for energy generation, a good estimate of the current field in the vicinity (e.g. 500m radius) of the tagged animal is essential for DR to be accurate. This may be especially challenging if the current is highly dynamic or varies spatially. As error builds with time, frequent positioning during dives, e.g., using a passive acoustic tracking system (see the next section), would reduce errors.

### 3.2.4 System readiness

GPS/GSM tags are available 'off the shelf'. To reduce data latency and for use in areas with low GSM coverage, a dedicated link from a GPS tag to a shore- (or turbine-) UHF receiver can be established Sensors to facilitate DR have been developed and implemented in a number of retrievable tag types. Examples include the D-Tag (Johnson & Tyack 2003), the Animal Diary tag (Wilson *et al.* 2007b) and the Little Leonardo series of data loggers (Mitani *et al.* 2004). However the combination of the two systems to provide inter-fix dead reckoning would take significant development time due to the need for on-board processing of raw sensor data. However, the major drawback is the requirement to accurately predict water current in time and space[6] – without which the combined GPS/GSM and DR tag is not a feasible option.

## 3.3 Passive acoustic monitoring (PAM)

Many marine mammal species use both passive and/or active acoustic detection as a means of sensing their environment; dolphins and porpoises in particular produce echolocation clicks for navigation and finding prey and these potentially provide a means of locating and tracking individual animals in 3D space. It is therefore possible to use passive acoustic monitoring systems mounted on, or in the vicinity of, tidal energy devices to localise the vocalisations of cetaceans swimming around the devices.

### 3.3.1 Vocalisation

Harbour porpoise (*Phocoena phocoena*) are the most likely cetacean to be present in the same areas as tidal turbines in European waters. In addition several species of dolphins may also be present. Porpoises produce trains of characteristic narrow band ultrasonic clicks (peak frequency @140kHz) which are projected forward in a narrow beam (3dB beam width of 16˚) and have an on-beam source level of 178-205 dB re 1μ Pa p-p (Villadsgaard, Wahlberg & Tougaard 2007). The primary function of these clicks is *echolocation* and click rate varies with behaviour and the echolocation task being undertaken. Click rates typically vary between 5 and 35 clicks per second but can reach rates of over 1000 clicks per second (Clausen *et al.* 2010). In the wild porpoises vocalise frequently, with 90% of intervals between clicks are less than 20 seconds (Akamatsu *et al.* 2007). Several species of dolphins are also found in inshore waters and are likely to interact with tidal energy devices. They produce communication whistle vocalisations as well as echolocation clicks. Their clicks are louder and have a broader bandwidth than those of porpoises and their rate of click production may be more variable.

[6] We estimate that the current vector prediction should be (+- 0.2m/s, +- 5°) of truth and available at a spatial (x, y, z) scale of 5-10m.

### 3.3.2 Mode of operation

Passive acoustic systems have been used extensively for detecting vocalising animals[7] but their use to localise and track animals is less well developed. The location of a vocalising animal can be determined from the time difference for a sound arriving at two or more hydrophones (Time Of Arrival Differences -TOAD). A single TOAD from a pair of hydrophones allows the location of the sound source to be determined along a hyperbolic surface of infinite area.

Arrays with a larger number of sensors provide a greater number of TOADs. In fact for an array with N sensors there are N*(N-1)/2 time of arrival differences, each of which will provide a hyperbolic surface; however, only (N-1) of these will be independent. The location of the acoustic source is estimated as the (theoretical) point where these surfaces cross. Hence at least two independent time delays are required to calculate a source location in two dimensions and three time delays (requiring a 4 sensor array) to provide a three dimensional location.

Simple two hydrophone towed arrays are now used routinely to carry out passive acoustic line transect surveys for marine mammals. However, because this type of array is towed, and therefore moving, a sequence of detections results in a series of surfaces all of which cross at a common location. This allows a range to the vocalising animal to be estimated, which is key information for line transects using distance based methods. However with a spatial precision of many tens of meters it is unlikely to be a practical method for investigating fine scale responses at these sites. In addition the required boats are both expensive and likely to affect the behaviour of the subjects. We thus focus on static hydrophones in the remainder of this section.

### 3.3.3 Accuracy

The accuracy of locating an acoustic source depends on a range of factors including the physical environment, the array design, the accuracy with which the hydrophone locations are known and the acoustic behaviour of the marine mammals being studied. Changing sound speed profiles within water masses which results in acoustic refraction leading to curved sound paths and a number of concomitant errors. However, these effects are less likely to be a problem in strong tidal current areas where waters are well mixed. Also reverberation, background noise and the directional nature of cetacean vocalisations can all result in variable signal waveforms at different hydrophones within an array, often introducing timing errors. In addition, for towed arrays and other configurations where the hydrophones are not rigidly fixed, error in the location of the hydrophones is a substantial potential source of error.

Generally, the effect of these errors is determined by their magnitude in proportion to the size of the TOADs themselves. Larger arrays will therefore, tend to provide

[7] For example the C-POD (http://www.chelonia.co.uk).

more reliable locations than smaller arrays. As a rule of thumb, the range that good locations may be estimated is about ten times the maximum dimension of an array. However large array dimensions can bring their own problems. Some stem from the practical difficulty of deploying and maintaining a large rigid array in an extremely energetic marine environment whilst others relate to the nature of the signals themselves. For example, cetacean echolocation clicks are highly directional, so as two hydrophones are moved further apart the waveforms received on each hydrophone will become increasingly dissimilar resulting in increasing timing errors. With large separations and low received levels it is likely that some clicks will be detected on only a subset of hydrophones raising concerns about the practicality of tracking cetacean movements using widely separate hydrophones. This issue was explored empirically as part of a Scottish Government funded project by deploying a large 3D array (dimensions ~20m) on a fish farm (a cost effective means of deploying a large floating array in porpoise habitat) which showed that it is possible to detect coherent clicks from porpoises within 150-200m range. We were able to localise and track animals, although the fact that the hydrophones were not rigidly fixed in this array compromised location accuracy that could be achieved. Most importantly, the exercise has served to demonstrate empirically that sufficiently coherent clicks are detected at multiple hydrophones in an array sufficiently large to allow tracking within a few hundred meters.

Based on simulations and modelling, we estimate that a rigid 3D array with dimensions of tens of metres is required to achieve sufficient accuracy (better than 1m) to examine interactions with an underwater turbine. It would be challenging and expensive to provide a structure to hold sensors in an appropriately configured array in high energy tidal areas. However, many turbine designs include substantial support structures that could provide a cost effective rigid support for an appropriately sized array (suitable examples include, ANDRITS HYDRO Hammerfest HS1000, Atlantis, Tidal Energy Delta Stream device, Open Hydro and Voith Hydro). Field data collected in pilot studies permits the performance of different array configurations to be modelled (for example see Ehrenberg &Steig (2002)).

Hydrophones need to be synchronised to determine TOADs with appropriate accuracy and this will require either all the hydrophone signals to be brought to a single digitising system, or remote digitising systems to very precisely synchronised, almost certainly through a connecting cable or fibre. Where turbines have appropriate large support structures and the incorporation of hydrophone arrays are planned from an early stage, it should be feasible to deploy systems with multiple rigidly fixed hydrophones which are hard-wired to a single digital acquisition device within the structure, with digital data being streamed ashore for detailed analysis. However, this may not always be feasible, and is clearly limited to data collection once the turbine has been installed. One possible solution to this would be to deploy clusters of hydrophones in small arrays of the order of a meter or so with waveforms and/or click detections being recorded autonomously within each cluster. TOAD analysis of these synchronised signals within clusters would provide accurate and unambiguous bearing and azimuth data for vocalising animals, and "crossing" such 3D bearings from multiple clusters deployed around a tidal turbine should provide locations and tracks for vocalising animals. While these locations might be less accurate than those that could be provided from a larger rigid array of synchronised hydrophones, they should still provide data of value for management applications. A system like this should certainly reveal avoidance and larger scale evasion at a scale of meters to tens of meters, but probably not at sub-meter accuracy.

#### 3.3.4 Data processing and latency

Systems incorporating hydrophones that are wired to shore, perhaps including basic signal processing offshore will provide the raw data (clicks or waveforms) in real time. Processing required to detect and characterise signals should also run in real time, especially in the case of porpoise clicks and active acoustic tags which have very characteristic signals. Currently the next step of calculating 3D location for these detections and joining them into tracks requires substantial user input and a time lag of several minutes would be expected, even if an experienced operator was on duty 24-7. The main need for real time data would be as part of a mitigation procedure involving a shut-down, or some other action such as activation of an acoustic alarm, if an animal came within a zone where it was believed to be at risk.

Hydrophone clusters (discussed above) and autonomous data loggers have to be recovered periodically and the data amalgamated. Thus they do not provide real time information.

#### 3.3.5 System readiness

Although the type of systems we describe here have never been deployed in tidal current areas, we have, in large part with Scottish Government support, been making progress in developing some of the essential software that would underpin a system like this and in addressing some of the key uncertainties. Thus, software routines which are highly relevant to 3D tracking have been developed within PAMGUARD, in the first place to analyse vertical array data, and the work deploying large arrays at fish farms mentioned earlier, addressed many concerns about the practicality of tracking porpoises with arrays of the order of 20m or so. Additional programming will be required to marshal and archive the huge amounts of data that such a system could provide and substantial software development might be anticipate to achieve a goal or real time automated localisation and tracking[8].

The hardware required consists of hydrophones, signal conditioning units and digitisers. It is also likely that digital signals will be converted to optical to facilitate bringing the signals ashore. The exact configuration will in part depend on the particular opportunities and constraints of each deployment. However, generic discussions with turbine engineers indicate that there will be sufficient room within the waterproofed chambers of the structure to be able to accommodate off the shelf

[8]SMRU Ltd is developing useful functionality in this area to support its PAMBOUY products

digitisers, signal processing and computers and network equipment. However this requires appropriate planning and early cooperation from the developer

We are working with one developer, TEL, to deploy a system with these capabilities in spring 2013, using largely off the shelf equipment. Thus, there seems no reason why such systems should not be considered within the time frames of the earliest commercial developments in Scotland.

### 3.3.6 Detection of acoustic pinger tags

So far, only localisation derived from the animals' own vocalisations have been considered. Grey and harbour seals do not regularly and predictably vocalise underwater, but they could also be locally tracked with a passive acoustic array if fitted with acoustic pingers. These could either be glued to the seal's fur or attached to flipper tags. Care must be taken with the choice of tag frequency in order that they are not detected by the seals (this is expanded in the active sonar section below).

Acoustic pingers are routinely used to track fish (Cooke *et al.* 2011) and a variety of tags and receivers systems are available. A number of companies offer bespoke solutions with the potential to track suitably tagged seals[9]. For example Wright et al. (2007) monitored the locations of tagged harbour seals in an estuary using a fixed array of 15 acoustic receivers. Harcourt et al. (2000) and Simpkins et al. (2001) used similar a similar technique to study the movement of polar seals in relation to breathing holes in ice. However none of these deployments had to contend with the challenges of strong tidal currents.

At any site at which there was the possibility that small cetaceans would be present, it would make most sense to establish an array of hydrophones for cetacean tracking (as discussed above), and incorporate detectors for individually coded acoustic tags into the detection and classification software. As the tag signals can be designed to be optimal for localisation and have a distinctive signature tracking them with the array should be somewhat easier than tracking small cetaceans. Calculations based on a 'typical' fish acoustic tag suggest that a static hydrophone array (of the type discussed above) running PAMGUARD[10] detection software should be able to identify a tag at a range of up to 200m. For tracking, the useful range should be about 10 times the array dimension. That is, an array with a foot print of 20m across should be able to track out to 200m. This would require tag-specific PAMGUARD detection module to be designed and the cooperation of tag manufacturers to release the details of their tag coding systems. However such an array would have the benefit of being able to track both vocal cetacea and acoustically tagged individual seals.

[9] Examples include: http://www.vemco.com/, http://www.oceantracks.csiro.au/tags-acoustic.html, http://atstrack.com/Generic-84-Acoustic-Fish.aspx, http://www.htisonar.com/index.htm, http://www.lotek.com/acoustic-positioning-software.pdf, http://atstrack.com/Generic-112-Systems-Acoustic-Fish.aspx

[10] http://www.pamguard.org/

Acoustic pingers are an order of magnitude cheaper than GPS/GSM tags (£100-300 compared with £3000). Thus a greater number of seals could be tagged. An extra advantage is that their small size may permit acoustic tags being attached to the flipper webbing, and thus they would not detach at the annual moult.

## 3.4 Active sonar

Active sonar is like underwater radar, but uses sound rather than radio waves. In recent years, there has been rapid development of active sonar systems for a wide range of uses. These include underwater imaging in low visibility and diver intrusion into secure zones.

The mode of operation is, in essence simple. Pulses of sound ('pings') are produced electronically using a sonar projector and the system then monitors for echoes of these pulses as they reflect off objects using one or more hydrophones. The speed of sound in water divided by half of the echo delay provides distance to target. To measure the bearing, several hydrophones are used to measure the relative arrival time at each, or with a receiver array of hydrophones, by measuring the relative amplitude in beams formed through a process called beam-forming.

Sonar efficiency can be affected by variations in sound speed, particularly in the vertical plane. The speed is determined by temperature, salinity and pressure. Furthermore, scattering from small objects in the sea, from the seabed, and from the surface can be a major source of interference. Together, these effects can make using active sonar to detect and track marine mammals in energetic tidal areas particularly challenging.

### 3.4.1 Available systems

There are a large number of commercially available active sonar systems. A recent review collated an inventory detailing over 200 systems from 39 sonar manufacturers (Hastie 2012). These are designed for a wide range of uses including mapping (e.g. with swathe bathymetry), underwater navigation, fisheries research, and seabed profiling. Fundamental transmission frequencies typically range from 12 to 2,250 kHz. Source levels were also provided by manufacturers of 99 of the systems and ranged from approximately 187 to 237 dB re 1µPa at 1m. Twenty four systems incorporated automated target detection and tracking software; however, most of these were designed for vessel or port security rather than for marine wildlife tracking.

To be able to measure the behaviour of marine mammals around tidal energy devices, a sonar system must meet a number of essential specifications including:

- Appropriate spatial coverage (both horizontally and vertically); this effectively determines the volume of water that can be monitored around the turbine.
- Sufficient temporal resolution (ping rate), angular and range resolution to allow marine mammals to be effectively detected, classified, and tracked.

- No interference with the behaviour of target and non-target species.

### 3.4.2 Target strength

The system must have a reliable detection capability, which depends on the proportion of sound that is reflected by the animal back to the receiver array. This is often termed the "target strength" and is frequency dependent and is usually expressed in decibels (dB). For smaller marine mammals, there are few empirical target strength data available. However, Au (1996) reported that the target strength of a stationary bottlenose dolphin under controlled conditions was relatively low, with mean broadside target strengths ranging from −11 to −24 dB dependent on transmission frequency. Most acoustic energy was reflected from the area between the dorsal and pectoral fins, corresponding to the location of the dolphin's lungs. Similarly, Doksæter et al. (2009) measured target strengths of 22 marine mammals (assumed to be dolphins or small whales) from a seabed mounted Simrad EK60 (38kHz); mean target strengths ranged from -5 to -35 dB, with an overall mean of -20 dB. Target strength measurements such as these provide an indication of the effective range over which a marine mammal species could be detected by sonar and also potentially provide a basis for discriminating marine mammals from other marine targets (e.g. fish, debris). Air, for example in the lungs, is compressed with increasing pressure as animals dive deeper. As noted above, air sacs may make the largest contribution to target strength and consequently target strength of marine mammals with decrease with depth.

### 3.4.3 Frequency choice

Most marine mammals rely heavily on sound as a means of navigation, and for detecting prey, and the hearing and vocal ranges of many species overlap with the transmission frequencies of many of the commercially available sonar systems (approximately 12 to 150 kHz). Thus appropriate active sonar frequencies must be chosen to avoid potential negative impacts including from auditory injury (Southall *et al.* 2007), changes in behaviour (Richardson *et al.* 1991) or interference with communication (Fristrup, Hatch & Clark 2003). While an animal's hearing may be most vulnerable to damage from sounds within its auditory range, intense sounds outside this range can also cause damage. Similarly, although the fundamental frequency of a sonar signal may be above the auditory range of a marine mammal, the source may also produce, unwanted, lower frequency energy which may be audible. Therefore, when considering the choice of active sonar, it is important to review the auditory capabilities of both the target and non-target species. These capabilities vary significantly between marine mammal species. For example, harbour porpoise hearing threshold at 1 kHz is about 80 dB re 1μPa (Kastelein *et al.* 2002), while it is about 26 dB re 1μPa for harbour seals. This means that a sound with a pressure level of 80 dB re 1μPa and a frequency of 1 kHz would be relatively loud to the seal (Kastak & Schusterman 1998). However, the same sound be perceived as barely audible to the porpoise.

### 3.4.4 System tests

Although a number of published studies have used active sonar to measure some aspects of marine mammal behaviour (Nottestad *et al.* 2002; Benoit-Bird & Au 2003; Benoit-Bird, Wursig & McFadden 2004; Doksaeter *et al.* 2009; Gonzalez-Socoloske, Olivera-Gomez & Ford 2009; Gonzalez-Socoloske & Olivera-Gomez 2012), none have measured fine scale marine mammal interactions with tidal turbines.

In a recent study of marine mammal interactions with tidal turbines, two 375 kHz manually-scanning sonar systems (Tritech Super SeaKing[11]) were deployed on the SeaGen 1.2 MW tidal turbine at Strangford Narrows (Northern Ireland) in the vicinity of a harbour seal colony (Hastie 2009). The primary aim of the study was to evaluate:

- The efficiency and reliability of the sonar as a monitoring and mitigation tool for marine mammals on an operational tidal turbine.
- The frequency of close range interactions between marine mammals and tidal turbines, and to compare movement metrics of marine mammals and other mobile targets as a basis for automated classification of marine mammals.

A total of 135 hours of real-time monitoring was carried out using a combination of visual and active sonar techniques. In all 72 marine mammals were sighted close to the turbine; this compares to a total of 87 other mobile targets that were detected using the active sonar. Comparison of the sonar targets to the spatial and temporal information on sightings made by the visual observer information suggested that a number of the sonar targets (22 targets; 16% of all targets) were marine mammals. These included harbour seals, harbour porpoises, and grey seals. The overall target detection rate was 1.18 targets per hour while the rate for confirmed marine mammal targets was 0.16 per hour. When sightings of marine mammals within the area covered by the sonar were compared with sonar targets, the percentage of sightings that could be matched with sonar targets was 46.7%.

The results of this study illustrate that small marine mammals (and other mobile targets) can be detected in a tidally turbulent water column in real time using sonar up to ranges of around 50m. The relatively low detection rate (46.7%) is potentially due to limitations with this sonar system (e.g. poor temporal and spatial resolution) and to the inherent problems associated with high frequency acoustics in tidal environments and targets close to the water surface. It is known that the highly heterogeneous water characteristics (e.g. density) near the surface or wind generated clutter (Kozak 2006) can have significant impacts on the imaging capabilities of sonar.

Although the initial results of these trials were encouraging (Hastie 2009), it was clear that a certain amount of development was required to produce an effective

[11] http://www.tritech.co.uk/product/mechanical-scanning-sonar-tritech-super-seaking

sonar system for use around tidal turbines. Hastie (2012) therefore carried out an R&D study in collaboration with sonar manufacturers to develop a system. Through correspondence with 39 sonar manufacturers and subsequent behavioural response tests with captive grey seals and wild harbours seals, and field validation trials, the Tritech Gemini system was chosen to be developed and trialled on a tidal turbine.

The Tritech Gemini[12] is a 720 kHz forward looking multi-beam sonar that is designed for detecting objects in the water column. It is a 2D system that allows detection and localisation of objects in the X-Y plane but does not provide information on the depth of the target. It has the following features:

- update rate: between 7 and 30Hz
- angular range resolution: 0.5°
- range resolution: 0.8 cm
- horizontal and vertical swathe widths: 120° and 20° respectively (up to 4 heads can be synchronised by pinging in sequence)

### 3.4.5 Data processing

Post-processing detection and classification software (SeaTec) was developed (by Tritech software engineers with input from SMRU Ltd) that used target similarity to a marine mammal (using flood-fill techniques), tide-weighted target velocity, and target path to estimate the likelihood that a target was a marine mammal. Field tests near a grey seal colony suggested a reliable (probability >0.95) detection range of around 44 m. Classification in real time using the SeaTec software was encouraging with all marine mammals being correctly classified. However, it tended to be relatively conservative with a proportion of other targets (such as floating logs or buoys) also being classified as marine mammals. Further post hoc processing can be carried out to refine these classifications and successfully reduce false positives; however, this currently requires user-intensive manual analysis.

In 2011 this Gemini system was trialled on the 1.2 MW turbine at Strangford Narrows. Over a period of 42 days a total of 109 targets (average of 5.9 per day) were classed as ‘highly probable marine mammals’ by processing with the SeaTec algorithms in real time and running the post hoc analyses on the results (see Figure 1). It should be noted that although there were no external data (e.g. visual observations) for validation of these targets, the raw sonar data for a proportion of the targets were reviewed and in most cases appeared to be marine mammals. As described above, there was scope for improvement through automation of the *post hoc* classification analyses.

### 3.4.6 System readiness

It is clear that active sonar can be used to detect and track marine mammals in the vicinity of fixed structures such as tidal turbines. However, few off-the-shelf systems

[12] http://www.tritech.co.uk/product/gemini-720i-300m-multibeam-imaging-sonar

have the spatial and temporal resolution, range and 3D detection capabilities required to track marine mammals. Furthermore, it is critical to carefully consider the acoustic characteristics of the system and the hearing ranges of the species of interest in order to avoid difficulties in teasing apart responses due to the turbine with responses due to the sonar. The main task now is to improve and automate the marine mammal classification process to reduce the level of manual post hoc analyses[13]. Also, active acoustic systems are directional and multiple units (which will need to be synchronised to avoid interference) may be required to provide good coverage.

# 4 Impact detection

It is unlikely that the technologies discussed above will be able to distinguish between an impact and a near miss. Yet this information is essential in assessing whether the observed movement behaviour resulted in successfully avoiding an impact. There is currently no proven way to directly detect the impact of a rotating blade against a marine mammal. However we consider here two approaches: mechanical sensing and video surveillance.

## 4.1 Mechanical sensing

Turbine blades are usually fitted with a variety of stress and acceleration sensors that are used to monitor the engineering performance of the device. Whilst is has been suggested that these sensors should detect a marine mammal strike, there has been no empirical test of this claim. If mathematical modelling suggests this is at all feasible, we suggest that this claim should be tested. Such a test could be based on a dead carcasses of similar appropriate mass (e.g. a pig) being presented into a rotating turbine. Such tests would determine the false-positive and false-negative detection rates. If successful, automatic (near real time) algorithms could be developed and used to trigger detailed examination of data collected from other sources at the same time. If proven, such a mechanical based system would be easy to deploy on large numbers of operational turbine, at relatively small cost.

## 4.2 Video surveillance

A video recording system can be deployed on a seal, or operated remotely underwater in the vicinity of a turbine.

### 4.2.1 Animal-borne video surveillance

Animal-borne video surveillance (for example, Davis, Hagey & Horning 2004) are widely used to infer prey types. However the large amounts of video data collected (albeit the operating duration is only a few days) precludes data relay (Hooker *et al.* 2008). Thus the device must be physically recovered to download data, either by recapturing an instrumented seal or by recovering a remotely detached device.

[13] This will require about two weeks of programmer effort.

The expense of the 'seal-ruggedized' camera systems and the low probability of an instrumented individual seal both interacting with a turbine (within the limited operating duration) and of successfully recovering the device preclude this approach as a practical option for UK grey and harbour seals. Furthermore it would be difficult to accurately reconstruct a track from such video data with few, if any, static geo-referenced features in the images.

### 4.2.2 Static video surveillance

Remote cameras have been used occasionally to monitor the local underwater activity of marine mammals (for example Simila & Ugarte 1993; Herzing 1996). However two issues limit their ability to observe marine mammal interactions at turbines. First, underwater visibility is usually too poor to allow sufficient range (and field of view) to monitor a complete turbine device. Visibility may be further reduced by the build-up of bio-fouling on the lens port. Second, video surveillance would require an artificial light source at night, a time when close interactions may be different. Artificial visible light at night would preclude the ability to investigate true night-time interactions. Infra-red (IR) light, whilst invisible to marine mammals, is very rapidly absorbed in sea water. However the recent availability of high power IR light emitting diodes (LEDs) and ultra-lowlight camera systems[14] may make warrant a practical re-investigation of the suitability of underwater video surveillance systems.

Notwithstanding these limitations, traditional video surveillance may have the potential for detecting impacts when the environmental conditions (daylight, good visibility and lack of bio fouling) allow. During these environmental windows it could be used to help interpret the fate of animals detected in the vicinity of the turbines using the other technologies. Detection events from these other technologies could be used to trigger the detailed examination of video sequences. Experience at EMEC suggests that this approach may have potential.

# 5 Discussion

## 5.1 Fine scale movement technologies

We have reviewed the applicability of three generic types of technology to investigate fine scale behaviour in the immediate vicinity of an underwater turbine. These are: animal-borne tags that collect and relay ashore individual's movement data, static active sonar and static passive acoustic arrays.

Our target specification for such a system is: a range extending to 100m of a turbine, a temporal precision of 1s and a spatial precision of 1m. This specification is not immutable. As we summarise below, however, a synergy of techniques should

[14] For example the Hitachi KP-DE500 Ultra High Sensitivity Camera.

approach our target specifications. However the only way to determine system performance is to test it under field conditions.

### 5.1.1 GPS/GSM tags

GPS/GSM tags have the advantage of describing movement and behaviour where ever tagged seals go – and not just in the vicinity of the turbine. But seals caught and tagged near a turbine may not subsequently visit the turbine area. This may be in part a function of individual variability and small sample size. At the Sound of Islay a study of harbour seals indicated that 30% of the locally tagged individuals remained in the Sound and close to the area of the proposed turbine array. This figure is used in Table 1 to illustrate the 'plausible sample size'. We therefore suggest a sample size > 20 seals is required to provide sufficient statistical power to infer population behaviour. Grey seals tend to move greater distances (McConnell *et al.* 1999) and thus have a greater risk emigrating from the tagging area.

However GSM/GPS tags on their own do not provide data of sufficient spatial and temporal resolution. The incorporation of dead reckoning to provide detailed underwater tracks depends upon a detailed knowledge of the current dynamics. Moreover, the incorporation of dead reckoning into GPS/GSM tag will require about a year of development and testing.

### 5.1.2 Passive acoustic monitoring

A passive acoustic monitoring (PAM) array fixed in the vicinity of a turbine can acoustically detect and track vocalisations of odontocetes and seals fitted with acoustic pingers at the required temporal and spatial resolution. A substantial engineering and financial effort is required to establish a local hydrophone and data processing. Thus it is sensible to use this investment to also track seals tagged with individually-coded acoustic pingers. Whilst there still is a risk that locally tagged seals may not visit the vicinity of a turbine, the relative cheapness of acoustic pingers means that a greater number of seals can be tagged. Vocalising baleen whales may also be tracked, but the uncertainty in their vocalising patterns means that there would be an unknown rate of false negative detections.

### 5.1.3 Active sonar

Active sonar is akin to underwater acoustic radar. It has been proven to detect and track marine mammals in the vicinity of underwater turbines at sufficient spatial and temporal scales. It is good at detecting both seals and cetacea and viewing the raw data usually allows distinction between a seal and an odontocete. However, this discrimination is vastly improved if used in combination with the species specific (or to individual specific if acoustically tagged seals are available) PAM systems. Active sonar is the only technology that will detect and track baleen whales.

### 5.1.4 Marine mammal classes

We consider three classes of marine mammals: 1. seals, 2. toothed whales (odontocetes) and 3. baleen whales (see Table 1). UK seals and baleen whales may occasionally vocalise, but these events are sufficiently rare or unpredictable that they cannot be used reliably to detect and track animals with a PAM system. Thus the only technique applicable to baleen whales is active sonar. Odontocetes, however, frequently vocalise and thus may be readily tracked in the vicinity of a PAM array. Seals (unlike UK cetacea) have the advantage of being readily caught and fitted with active tags – including acoustic pingers which can be tracked with PAM arrays.

### 5.1.5 Suggested system configuration

To balance the strengths and weaknesses of the above technologies we suggest that the following generic configuration represents the best probability of achieving the overall objective:

- Establish of a static PAM array around one or more turbine to track vocalising odontocetes.
- Tag local seals with acoustic pingers so that they can also be detected and tracked by the PAM array.
- Establish one or more active sonars on the turbine to detect and track all marine mammal species (including baleen whales).

## 5.2 Impact detection technologies

None of the technologies discussed above is likely to provide data of sufficient quantity and quality to confidently distinguish a collision from a near miss. Yet impact detection is essential to interpret fine scale movements. For example, which of the close interactions recorded by the tracking technology result in an impact?

Whilst video surveillance has distinct limitations (water turbidity, bio-fouling and not functional during darkness) it does provide a potentially powerful detection capability when conditions allow. Recent developments in low light level camera technology might extend usefulness well into the twilight hours. Mechanical detection, using inbuilt accelerometry and strain sensor on the turbine blades, is not limited to favourable environmental windows. Also, it would be a cheap system to employ. However its potential (or otherwise) has yet to de demonstrated.

### 5.2.1 Roadmap for evaluating impact detection systems

To detect direct impact we suggest pilot testing both systems:

- Establish two video cameras pointing up- and down-stream of the turbine. Evaluate whether the automatic detection software systems discussed in the PAM array section could be incorporated. The video surveillance system could be triggered by detection events from the active sonar and PAM systems.
- Test whether Mechanical Detection using the turbine's sensors will detect the strike of a carcass. This test should also be combined with video surveillance.

If successful then trigger logging of the turbine sensors with PAM or active sonar detection event.

## 5.3 High energy sites

Areas of high tidal energy offer both challenges and opportunities to study the fine scale behaviour of marine mammals. On the negative side they are areas of turbulent flow with unpredictable, though perhaps important, local eddies. The flow produces high levels of ambient noise which can interfere with techniques that use sound – either actively or passively. The high current and consequent higher erosion rates from suspended material increases the practical difficulties in establishing and maintaining hardware underwater.

However there are positive aspects. The establishment of a turbine means that the surrounding area will have been well surveyed, although perhaps not sufficiently for our purposes (see below). It is also likely that both power and high bandwidth communication channels will be locally available. In addition the actual structure of the turbine device may be made available for the attachment of hardware.

The information derived from the technologies considered here is only part of that needed to interpret fine scale behaviour and detection of impact. Generally we highlight the need for the larger scale distribution, movements and behaviour of the target species to be investigated. The background biology is essential. Similarly information about the local physical environment is required. This includes: detailed current and bathymetry, turbine construction and operation schedules, and turbine noise generation levels and local sound propagation models.

# 6 Tables

| technology | identify to species? | | | Identify to individual? | Precision (95%) | | plausible sample size | | data latency (min) | range (m) | Taxa suitability (seals, toothed& baleen whales) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | seals | odontocete | baleen | | space | time (sec) | Indiv | duration | | | |
| **GPS/GSM telemetry & dead reckoning** | yes | NA | NA | yes | 10-500 m | 10 | 30% of tagged | 6 months | <=2 days / 4 hours / 4 min with direct UHF link | global | seals |
| **Passive Acoustic Monitoring (PAM)** | no | yes | NA | no | 5 m | continuous | species density | indefinite | logged / 0 | 200 | toothed |
| **PAM & active tags** | yes | NA | NA | yes | 5 m | 5 | 30% of tagged | indefinite | logged / 0 | 200 | seals |
| **Active Sonar** | yes | yes | yes | no | angle resolution: 0.5°<br>range resolution: 0.8 cm<br>horizontal and vertical swathe widths: 120° & 20° respectively | 7 - 30Hz | species density | indefinite | 0 | 50 | seals<br>toothed<br>baleen |

**Table 1.** A summary of the attributes of each technology to detect and track seals in the vicinity of a turbine. The attributes are explained in the Candidate Technologies sub-section. NA=Not Applicable. The applicability to different taxa of marine mammals is shown in the 'Taxa suitability (seals, toothed &baleen whales'. The values are largely illustrative and the actual values depend upon the location of the study, technology configuration and the local density of marine mammals.

# 7 Figures

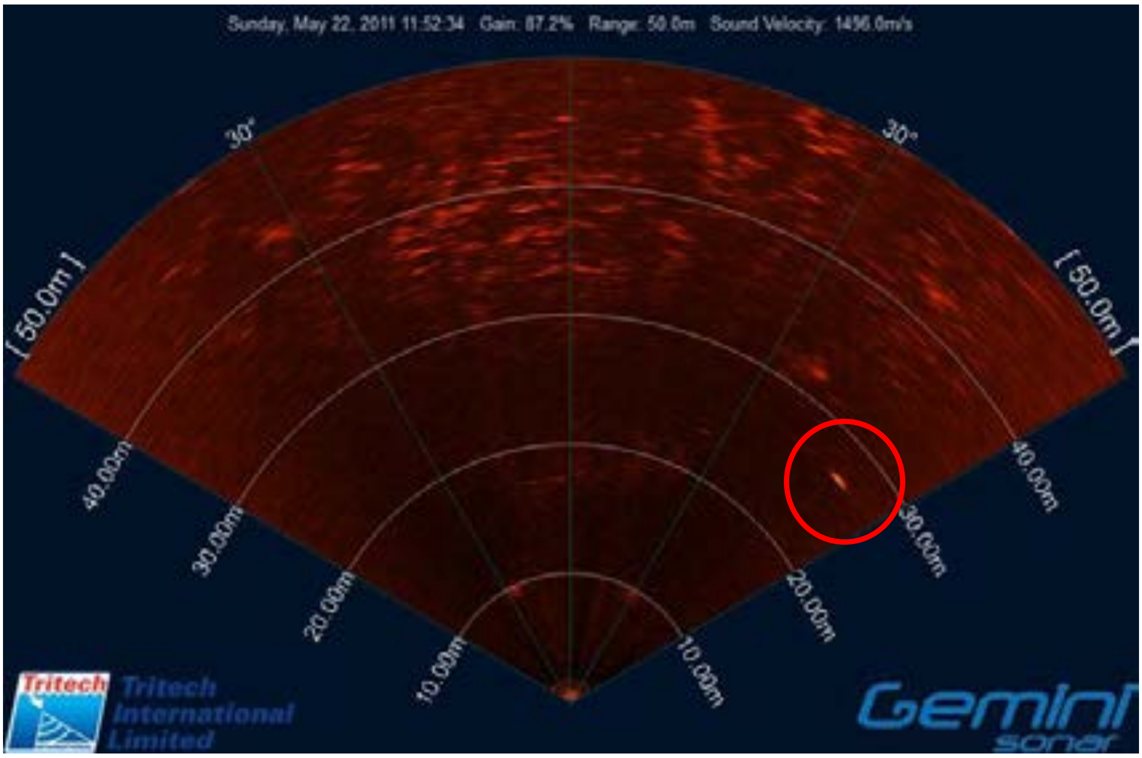


**Figure 1**: Sonar image of a detection that was classified as being a “highly probable marine mammal” (red circle). Taken from Hastie (2012).

# 8 Appendix 1: Report Remit

**Background**

**Feasibility Study: Methods for tracking the fine scale underwater movements of marine mammals in the vicinity of marine tidal devices.**

The Scottish Government has a target for 100% of Scottish demand for electricity to be met from renewables by 2020 creating a balanced portfolio of both onshore and offshore technologies. Offshore renewables have the potential to make a significant contribution to Scottish Government targets for delivery of renewable energy generation. The Scottish Government has the duty to ensure that the development of offshore renewable sectors is achieved in a sustainable manner in the seas around Scotland.

Strategic Environmental Assessments (SEA) on offshore renewable development has identified a need to evaluate potential interactions between offshore renewables and marine wildlife as a matter of priority so that appropriate mitigation can be investigated and applied. One concern with respect to the impact of tidal turbines on marine mammals is the potential for mortality or injury through collision with rotating turbines and the ability for marine mammals to take avoiding action. To evaluate the risk of such collisions means understanding the fine scale underwater movement of these mammals within the immediate vicinity of tidal turbines.

Existing technologies for tracking underwater movements are variable and include satellite telemetry, passive acoustic monitoring, active sonar and video techniques. Satellite telemetry devices have long been deployed on seals to answer a range of research questions, including how seals use the marine environment, foraging patterns, diving behaviour and temporal/spatial distribution. They have the potential to provide good spatial coverage but are restricted in terms of tracking fine scale underwater movements and, their reliance on being able to predict the movement patterns of individual animals which may rarely enter the areas of interest. Active and passive sonar have been actively employed in areas of tidal development (e.g., Ramsay Sound, EMEC, Strangford Lough), and when placed within the vicinity of the tidal devices may offer a more appropriate method for direct observations of potential collisions. Video can provide data on movements but may be restricted by limitations on underwater visibility due to local conditions (e.g., turbidity, light constraints).

The aim of this project is to review current and developing technologies for tracking the fine scale underwater movements of marine mammals in high energy tidal sites, and to test the feasibility of these technologies for direct observation of potential collisions. Possible development of new technologies should also be investigated where current devices may not be applicable.

**Objectives**

The objectives of the project are:

1. Review all current and developing technologies for tracking the fine scale underwater movement of marine mammals which are applicable to high energy tidal stream sites. The project should cover all options for fine scale tracking of marine mammals, including passive acoustic monitoring, active sonar, video and satellite telemetry devices.

2. Predict the feasibility of these technologies for direct observation of movements and possible collisions in high energy tidal stream environments.

The project will aim to answer the following questions:

- What technologies are current employed, or are in development, which have the ability to track the underwater movement of marine mammals? What are their strengths and limitations?

- Are these technologies fit for purpose and appropriate for tracking animals in high energy tidal sites and at a very local scale? For example, the Sound of Islay, Kylerhea.

- Can these technologies provide fine scale tracking in the vicinity of tidal turbine rotors? What is their sensitivity to describe small scale process (precision of location) and limitations?

- Are certain technologies appropriate to a particular species? Are there different requirements for seals, toothed cetaceans and baleen whales?

- Given the limitations of current seal tags (i.e., their reliance on the movement patterns of individual animals which may rarely enter areas of interest), are these devices appropriate for tracking movement on such small spatial scales (e.g., Sound of Islay area)?

- Taking account of the above questions, what current technologies can best provide the required information, or do we need to look at new technological developments?

- Will one technology provide the required information for direct observations of collision for different species groups or do we require a suite of methods?

A detailed case study for the use of such devices in the Sound of Islay for seals should be included.

**Approach**

It is anticipated that the successful contractor will develop the proposal in line with the aims and objectives of the project and the wider policy requirements. As a minimum, it is anticipated that the methodology would consist of the following research tasks:

- A desk study comprising a literature and data review into current technologies or proposed new technologies looking at the (fine scale) underwater movement of marine mammals. The review should include consideration of whether these technologies are appropriate for very localised studies at high tidal energy sites. Consideration of the practicalities of each technology for seals, toothed cetaceans and baleen whales should be considered.

- Utilising the information gained at the literature and date review stage, suggest practical and viable options for tracking the underwater movements of marine mammals.

- A case study for the most appropriate technology for the fine scale tracking of seals around turbines in the Sound of Islay should be included.

- Close liaison with experts in this research area (e.g., marine mammal behaviour) to ascertain that the respective methodologies meet requirements in terms of direct observations of mortality or injury is encouraged.

- The contractor is encouraged to expand and develop their ideas based on the information presented here to fulfil the project requirements in an optimum and cost effective manner.

**Outputs**

The contractor will be expected to provide the Scottish Government with the following outputs:

- A report which provides a detailed view of the current capabilities of existing and developing technologies to monitor fine scale underwater movement of marine mammals, taking account of existing ongoing work in this area. The respective strengths and limitations of the technologies, including their applicability to a range of tidal device areas, should be included.

- The feasibility of these technologies, or a combination of them, to answer questions on whether marine mammals will interact with turbine rotors and their ability to take avoidance action.

- The final written report should contain an executive summary, data reporting, background methodologies, conclusions and recommendations. Four copies of the draft and final reports should be supplied in hard copy and a disc copy of the final version in a format compatible with Microsoft Word. Potential contractors should indicate in their tender who will have the main responsibility for writing the report.

- A research summary. This should be a 2-4 page summary of the main findings of the research and should be produced separately from the final report. This summary should not be simply a bulleted version of the points in the main report, but should be a wider look at what the findings mean in a wider policy context and may be edited by the Scottish Government.

- The contractor will be expected to engage in a close working relationship with Marine Scotland Science, and the MS Renewables Team in order to promote discussion of project goals and their delivery. Engagement with the Sea Mammal Research Unit, DECC, EMEC and other parties involved in this field is critical.

# 9 Appendix II: Case study – Sound of Islay

To illustrate the use of the technologies discussed in this report we consider as a case study: the proposed deployment of an underwater turbine array at the Sound of Islay (Figure 2) by Scottish Power Renewables. We refer to this site as the Development Area. Details of this development provided in the appendix are taken primarily from Scottish Power Renewables' Environmental Statement (Scottish Power Renewables 2010b). The information provided in the case study reflects the position at the time of this reports preparation.

## 9.1 Proposed development

The Sound of Islay is approximately 1 km wide and reaches 62m in depth. The maximum flow within the Sound is 3.7m/s.

A total of 10 Hammerfest[15]1 MWattHS1000 turbines will be installed in 2013[16] (see Figure 3). They will be placed in water in excess of 48m deep and secured with gravity ballast. The tripod support structure dimensions are 15m (W) x 22m (L) on the substructure with a hub height of 22m from the seabed. A rotor diameter of 23m will give the device a total height from the seabed of approximately 33.5m. The rotational speed of the turbine will be 10.2rpm with a maximum blade tip speed of approximately 12m/s. Two subsea cables will connect the array with the grid – probably on the Jura shore.

## 9.2 Marine mammals

Both harbour seals and, to a lesser extent, grey seals (*Halichoerus grypus*) are present the vicinity of the Development Area. The South-east Islay Skerries is a Special Area of Conservation (SAC) for (approximately 600) harbour seals (*Phoca vitulina*) and lies about 18 km to the south of the Development Area. Approximately 50 harbour seals may be seen hauled out within the Sound of Islay. SMRU (unpublished) has shown that harbour seals from this and neighbouring haulout sites do transit through the Sound. Grey seals are more common to the north of the Sound and are a notified feature of the Oronsay and South Colonsay SSSI (20 km to the north).

Harbour porpoise (*Phocoena phocoena*), and the bottlenose dolphin (*Tursiops truncatus*) are the most common cetacea to use the Sound of Islay. Since there is uncertainty about the rate at which cetacea (and to a lesser extent grey and harbour seals) will transit the Sound we take the precautionary view that all marine mammal classes (seals, toothed and baleen whales) should be targeted in this proposal.

[15]http://www.hammerfeststrom.com/
[16] This date may be delayed.

## 9.3 Proposed monitoring scenario

### 9.3.1 Caveats and scope

Our proposal is generic. The details depend on:

- The scope of the objective. We take as a working objective: 'tracking fine scale underwater movements of marine mammals around marine tidal devices'. As such we ignore the larger scale questions of the rates of usage within the Sound of Islay and consequential population level effects.

- Cooperation with the operator during the construction phase (especially the provision of brackets to attach PAM hydrophones, active sonar devices or underwater cameras; access to electrical power and communication channels).

- The finances available. No costings are provided here, but we assume there are financial constraints. Thus we consider the minimum scenario (with consequent greater risk) to address the primary objective.

- Successful pilot trials of the technology.

### 9.3.2 Proposal

In consideration of the planned deployment, biology and technological tools available, we propose the following monitoring scenario for the Sound of Islay.

The ten turbines will be arranged linearly in pairs or triplets. We consider the turbine pair/triplet that is furthest upstream to provide the greatest number of interactions since they will be the first to be encountered. Since the leading structures will alternate with tidal flow we suggest that the detection systems be established at both ends.

- Establish a static PAM array around a turbine to track vocalising odontocetes. The raw PAM data will cabled ashore (probably to the Jura side of the Sound) where it will be processed and stored. An internet connection will permit subsequent remote data downloading and operation monitoring.

- Tag with acoustic pingers (type to be decided in trials) thirty harbour seals captured as close as possible to the turbine array. Interactions of these individuals may then be tracked with the PAM arrays. Furthermore, the availability of a PAM at either end of the array will indicate passage time of individual tagged seals along the length of array.

  Note that, whilst not the primary objective, an optional, additional tagging of these tagged seals with GPS/GSM tags would permit the interpretation of fine scale interactions within the context of larger scale movements.

- Establish a Tritech Gemini Active Sonar on the turbine to detect and track all marine mammal species (including baleen whales). As with the PAM array, data would be cabled a shore-based processing centre. Automatic detection software should be developed and established.

We suggest that the Sound of Islay would be an appropriate place to test Impact Detection systems. We thus suggest the following:

- Establish two video cameras pointing up- and down-stream of the turbine. Evaluate the operational environmental window of the video system. Evaluate whether the automatic detection software systems discussed in the PAM array section could be incorporated. The video surveillance system could be triggered by detection events from the active sonar and PAM systems.

- Model and test whether Mechanical Detection using the turbine's sensors will detect the strike of a carcass. This test should also be combined with video surveillance. If successful then trigger logging of the turbine sensors with PAM or Active Sonar detection event.

There is a risk that any impact detection system, even in it passes feasibility test, will fail to encounter a certain proportion of actual impacts. We thus suggest the following:

- A regular survey for carcasses is established around the neighbouring shores where the tidal current are likely to ground ashore any animal killed at the site of the turbine array.

A similar survey was established at Strangford Lough in relation to the establishment of a SeaGen turbine. No seal carcasses were found which presented trauma associated with blade strike.

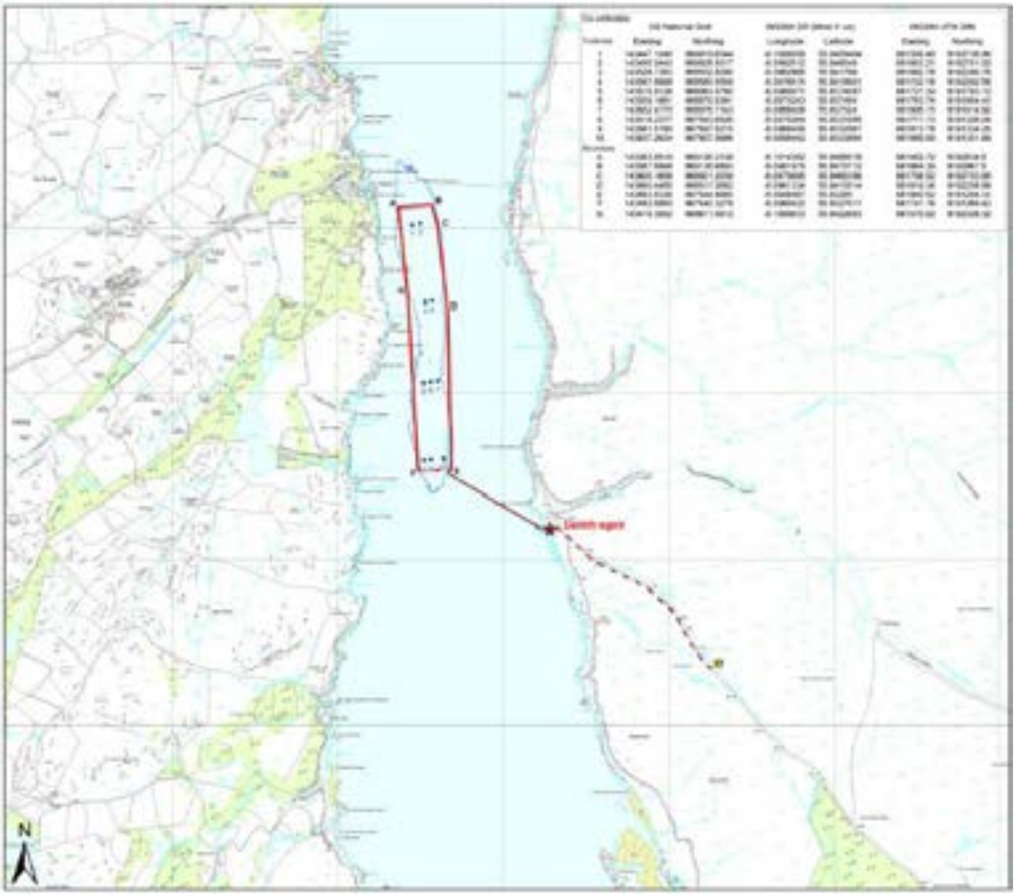

**Figure 2.**Site of planned deployment of 10 turbines within the Sound of Islay.  Taken from Scottish Power Renewables (2010b).

**Figure 3.** Artist’s impression of an array of Hammerfest HS1000 turbines. Taken from Scottish Power Renewables (2010a)

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