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Tracking porpoise underwater movements in Tidal Rapids using drifting Hydrophone Arrays. Filling a Key Information Gap for Assessing Collision Risk

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ABSTRACT

The growing interest in generating electrical power from tidal currents using tidal turbine generators raises a number of environmental concerns, including the risk that cetaceans might be injured or killed through collision with rotating turbine blades. To understand this risk we need better information on how cetaceans use tidal rapid habitats and in particular their underwater movements and dive behaviour. Porpoises, which are the most abundant small cetacean at most European tidal sites and we have developed an approach which uses time of arrival differences of narrow band high frequency (NBHF) porpoise clicks at hydrophones in an array drifting in tidal rapids, to accurately track their fine scale movements underwater. Extensive ground-truthing and calibration trials have been carried out that show that the system can provide depth and location data with sub meter errors and also indicate array configurations likely to provide the best balance of accuracy and practicality. Field data from porpoises apparently foraging in strong tidal current areas reveal contrasting behaviours at different locations. A recent surprising observation has been of porpoises diving to ~100m in the Corryvreckan/ Great Race

INTRODUCTION

Around the world, there is an increasing interest in generating renewable, low carbon electricity in the marine environment. Tidal power generation, which has the great advantage of being highly predictable, is being aggressively pursued in several regions with large tidal ranges and strong currents. However, this surge in anthropogenic activity in tidal rapid habitats brings with it concerns about environmental effects and a pressing need to better understand the biology of these habitats which are both unusual and seem to be important for some species [1]. Tidal rapids are challenging environments in which to work and, partly as a result of this and their limited spatial extent, they have been little studied. Many of the prototype and current tidal generators have large exposed turbine blades which rotating freely in tidal currents and may reach tip speeds of 10-12 ms^{-1} [2]. One specific concern related to this is the risk of collision between these blades and larger animals such as large fish and marine mammals [2]. If tidal areas are ecologically significant areas for foraging or other activities, the future deployment of large scale arrays of turbines could lead to habitat exclusion problems. At many temperate European and N. American sites harbour porpoises (*Phocoena phocoena L.*) are the most commonly encountered marine mammal species [3]. Predicting collision risk and determining the significance of tidal habits for harbour porpoises requires knowledge of the absolute density and distribution of animals in tidal rapid areas along with an understanding of their diving behaviour and underwater movements. Fine scale tracking of dives can be used to assess the likelihood that animals will "encounter" turbines and offers a unique insight into their behaviour and use of tidal areas.

Measuring porpoise dive depth and underwater behaviour in tidal rapid sites is challenging. Although there have been recent successes with tagging porpoises[4], telemetry is still difficult, invasive, expensive and has not been attempted in UK waters. Even if feasible tidal rapids are such a small proportion of the total available habitat for this species that it is very unlikely that any particular tagged individual would spend a significant proportion of time in areas of interest. For these reasons it was important to devise a system which could detect and track animals within a specified area.

Widely spaced hydrophone arrays have been used for decades to track the movements of cetaceans underwater[5 6]. By analysing the time of arrival differences between a vocalisation detected on multiple hydrophones it is possible to determine the position of the vocalising animal. Many studies have looked at reconstructing dive tracks using hydrophone arrays , a particularly apt example being the spiral dive profiles of Sperm Whales reconstructed using four widely separated drifting hydrophones in Kaikoura [7]. However, as cetaceans get smaller, the frequency of their vocalisations increase and localising using hydrophone arrays

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becomes more difficult. Higher frequency vocalisations attenuate in seawater faster; meaning the spacing between hydrophone elements has to be reduced. Time errors due to uncertainty in the positions of hydrophones and measurement of sound speed become much larger in proportion to the received time delays. The positions of hydrophones underwater must then be known more precisely and data from different hydrophones synchronised to fractions of a millisecond. Harbour porpoises produce amongst the highest frequency vocalisations (130kHz) of any marine mammal and hence these problems are particularly acute.

METHODOLOGY

Unpredictable currents, rough sea states and changing bathymetry means the deployment of hydrophone arrays in tidal rapids presents a particularly challenging problem. An ideal hydrophone array would consist of a fixed structure of at least four, but ideally many more, hydrophones separated in three dimensions with the positions of each element known precisely. A large number of hydrophones ensure that the directional clicks of a harbour porpoises and dolphins are picked up on multiple elements. Combined with a precise knowledge of the hydrophone positions this provides the optimal chance of accurately localising animals. In a tidal area any fixed array on the seabed would require a significant structure to survive currents sometimes exceeding 8 knots whilst any fixed structure on a boat would need to be rapidly recoverable and deployable. Both these options are expensive, complex, risk equipment damage and would require specially made structures.

A non-rigid vertical array of hydrophones deployed from a *drifting* vessel provides one practical solution for fine scale localisation in tidal areas. Such an array consists of a non-stretch rope with multiple hydrophones attached and substantial weight to hold it steady in the water column. It can be deployed and recovered quickly simply by using a winch allowing a drifting vessel to safely traverse tidal rapids. We constructed a vertical array consisting of 6 evenly spaced hydrophones (201 dB re 1uPa sensitivity, 28/40dB pre amps), the deepest deployed around 28m underwater. Using a non-rigid array in tidal areas introduces the potential for significant movement due to variable underwater currents and wind against tide acting on the vessel. This can introduce large errors in the position of hydrophones which in turn propagate to errors in the source location. Sensors to determine the movement and orientation of the array are therefore necessary to accurately determine possible errors. Our array used three Open Tags to measure orientation every 0.01 seconds, allowing us to model the underwater movements accurately over long deployment periods.

Although the vertical array is a practical tool in tidal areas it provides limited data. Any linear array of hydrophones is only capable of localising in two dimensions; in the case of vertically orientated arrays the location of the animal is restricted to a circle of possible locations, centred on and perpendicular to the array. Hence the depth and range of an acoustic source can be determined but it is not possible to calculate bearing information. This was addressed by rigidly attaching a ‘cluster’ of four or more hydrophones to the research vessel. This cluster of four hydrophones, separated by 30-50cm and deployed at a depth of 2-3m, allows a 3D bearing to the animal to be calculated thus providing full set of 3D co-ordinates when combined with the depth and range measurements from the vertical array. The close spacing of hydrophones elements within the cluster and shallow deployment depth allowed for quick deployment and recovery. A two axis inclinometer was used to measure the exact orientation of the cluster over all deployment periods. A vector GPS was used to determine the exact heading of the vessel.

Data from all ten hydrophones was bandpass filtered using ETEC and HP27 amplifiers, digitised using USB 6356 and 6351 sound cards and recorded to external hard drives using PAMGUARD.

Surveys took place in 2012 and 2013 in Orkney and Great Race.

Analysis

The positions of all hydrophones were determined by combining sensor data from the vector GPS, Open Tag sensors on the vertical array and inclinometer on the small cluster of hydrophones. MATLAB was used to model hydrophones positions. A typical set of positions is shown in Figure 1 showing substantial underwater movement of

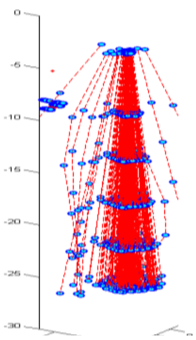

Figure 1. Modelled positions of hydrophones over a day’s survey effort. Array movement was determined by combining data from vector GPS, Open Tags, and an inclinometer. Blue dots show hydrophone positions .

hydrophone elements.

Data was then analysed in PAMGUARD using a new localisation module which can calculate locations for a single click detected on at least 3 hydrophones. The module is capable of distinguishing echoes, can deal with multiple vocalising animals present and utilises probabilistic MCMC algorithms to accurately estimate errors. Results from the module were then passed to MATLAB were a technique based on Kalman filters and Hungarian matching algorithms was used to convert individual localisation points into dive track fragments. We refer to 'track fragments' rather than dive profiles due to the fact that often the highly directional vocalisations of porpoises are not detected on the array (e.g. if a porpoise is facing away from the array or stops vocalising for a few seconds) and hence, rather than a full dive profile we get fragments of the profile. To an extent these can be interpolated but at a certain point this R interpolation becomes uninformed guessing.

OBSERVATIONS

The accuracy of the array has been extensively tested using a simulated porpoise vocalisation from an underwater speaker at known locations. Localisation results show sub meter errors when porpoises are close to the array, with a gradual increase in error as range from the array increases. The maximum effective localisation range of the array is around 250m.

Analysis of data from two surveys in 2012 and 2013 is ongoing but some initial results are available. Data showing dive profiles e.g. Figures 2 and 3, provides information on the proportion of time that animals spend at different depths and will clearly yield data that are relevant to collision risk. Generally porpoises show dives to depths of between 5 and 80 m and often seem to be diving to the seabed. Porpoises in the tidal rapids to the west of Corryvrecken were making occasional dives to depths of 100m or more.

CONCLUSIONS

We now have a reliable method to collect data on the fine scale movements of porpoises in tidal habitats. Open source software has been created to make the complex detection, classification and localisation algorithms widely accessible and the development of tracking algorithms has finalised the methodology. Currently a complex setup is required to collect the data, however with funding from a NERC Knowledge Exchange grant we are working on an open design autonomous buoy to allow consultant and other research groups to more readily collect such data. Analysis of 2012/13 field data is ongoing but should be complete by the end of 2014.

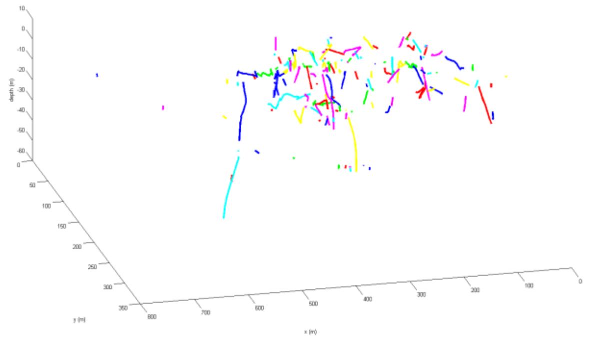

Figure 2. Example of 3D dive tracks collected over a 15 minute period drifting through the Great Race, west of Corryvrecken. Each coloured line represents one detected dive fragment.

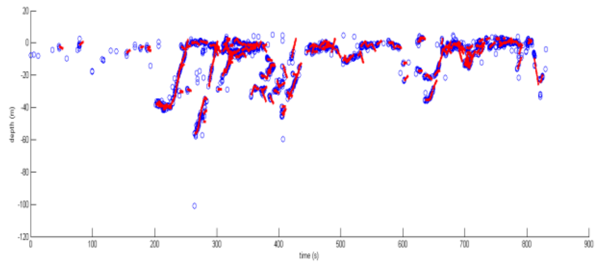

Figure 3. Dive profiles (depth v time) of animals from data shown in Figure 2. Blue dots show localised positions and red lines indicate interpolated dive tracks.

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