INTEGRATING A MULTIBEAM AND A MULTIFREQUENCY ECHOSOUNDER ON THE FLOWBEC SEABED PLATFORM TO TRACK FISH AND SEABIRD BEHAVIOR AROUND TIDAL TURBINE STRUCTURES

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INTRODUCTION

The drive towards sustainable energy has seen rapid development of wave and tidal stream (MRE) energy. However, little is known of any environmental and ecological effects [1]. The FLOWBEC-4D project developed an upward facing sonar platform to investigate how currents, waves and turbulence at MRE sites may influence the behavior of marine wildlife, how important collision risks might be, and how MRE devices (MREDs) might alter the behavior of wildlife [2]. Foraging efficiency (the capture of prey by a predator) is considered to be the major ecological driver of population dynamics, as it controls both adult and juvenile survival and condition [3]. Information was gathered on predator and prey use of MRE sites to identify and quantify which type of habitats (depth of water column, speed of tides, etc.) predators predictably use for foraging.

Although boat surveys can provide high-resolution coverage along specific tracks [4], it is not logistically feasible to monitor a high-energy site continuously at high-resolution for a 14-day tidal cycle. Wind, waves and tide reduce positional accuracy such that boat surveys cannot monitor fine-scale interactions of individual targets at the precise location of MREDs and the costs of long duration surveys are high. Surface platforms [5, 6] can reduce cost but are similarly limited because of their instability in high-energy sites. In both cases, there is also the risk that the boat/platform presence and noise (in air and under water) could affect the species being studied.

Mounting instruments on the MRED provides a stable mounting and simplifies power and data requirements for longer duration surveys. The interactions of fish with tidal turbines have been imaged using cameras but visibility (turbidity and illumination) limits both the range and survey time [7]. Active lighting will directly affect animal behavior. Acoustic instruments mounted on the MRED are adversely affected by turbulence within a few meters from the MRED itself, which can mask the presence and interactions of wildlife [8]. Conversely, an independent platform allows the instruments to be positioned a short distance from the MRED, recording the interactions of wildlife and also conducting baseline studies elsewhere under similar conditions, e.g. in an area free from MREDs or prior to MRED installation.

The FLOWBEC seabed platform (Figure 1) addressed these issues by integrating a number of instruments to record information at a range of

FIGURE 1. THE FLOWBEC SEABED PLATFORM

physical and trophic levels. Data were recorded at several measurements per second, for a duration of 2 weeks to capture an entire spring-neap tidal cycle at wave and tidal energy sites at the European Marine Energy Centre (EMEC). An upward-facing multifrequency Simrad EK60 echosounder (7° beamwidth, 38, 120 and 200 kHz) is synchronized with an upward-facing Imagenex Delta T multibeam (MBES) (120° x 20° beamwidth, 260 kHz) aligned with the tidal flow. An ADV measures current and turbulence, and a fluorometer measures chlorophyll (a proxy for plankton) and turbidity. The latest revision has integrated a Nortek Signature broadband 5-beam ADCP, an upward facing color video camera, and passive acoustic monitoring (PAM). The platform is self-contained with no cables or anchors, facilitating rapid deployment and recovery in high-energy sites and allowing baseline data to be gathered. Measurements from the subsea platform are complemented by a 3D hydrodynamic model and concurrent shore-based marine X-band radar and ground-truth wildlife observations.

The benefit of combining information from multiple instruments to increase coverage, sensitivity and the information available has been recognized elsewhere, as it also allows one instrument to trigger the recording of another [9]. In the case of FLOWBEC, co-registration of targets seen across acoustic instruments greatly increases the information available. The EK60 alone provides quantitative measures and patterns of target distribution [10], yet co-registration of the same target on the MBES, allows concurrent behavior and predator-prey or target-MRED interactions to be monitored. Targets co-registered on both instruments can be used as a training dataset to aid classification of targets detected on a single instrument.

Single/split beam, MBES and acoustic cameras have been evaluated previously for use in tidal sites [5, 11, 12]. However, turbulence can both mask ecological targets, and compound classification. This paper describes the development of novel processing techniques to mask surface-connected turbulence, extract biological targets for parameterization and tracking, and an example of the information gains from co-registering data between instruments.

TARGET TRACKING USING A MULTIBEAM SONAR

MBES target tracking comprises a number of steps: water column delineation, target detection, tracking and classification. Water column delineation is based on a static mask rather than detection of the surface and connected turbulent disturbances. Figure 2 shows the water column used for the 2013 deployment adjacent to the

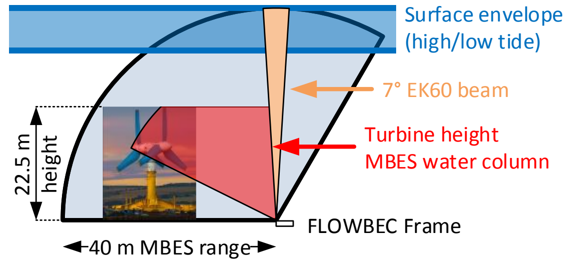


FIGURE 2. THE MBES SWATH WAS CROPPED TO DETECT TARGETS OVERLAPPING THE TURBINE STRUCTURE AND EXPECTED BLADE RADIUS.

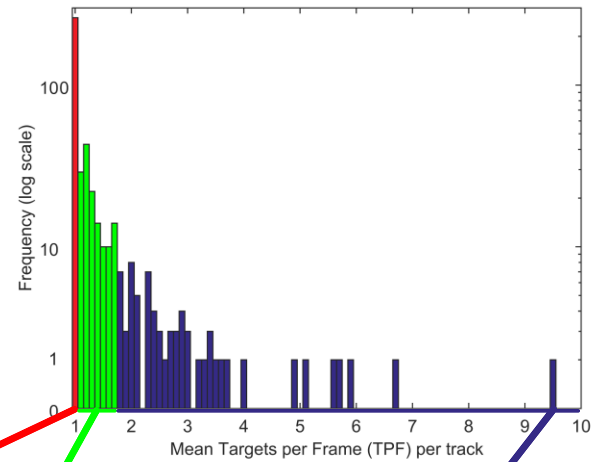
Atlantis AK-1000 turbine base and piling. In this case, the sector range is set to 30.4 m to exclude the turbulent surface and its reflections. Beams in the outer ±27° are removed to exclude the seabed, turbine structure and associated reflections. The remaining sector is then cropped to a height of 22.5 m to study targets overlapping with the Atlantis turbine structure and expected blade radius. Targets are tracked at ranges < 1 m and so no near-field cut off is applied.

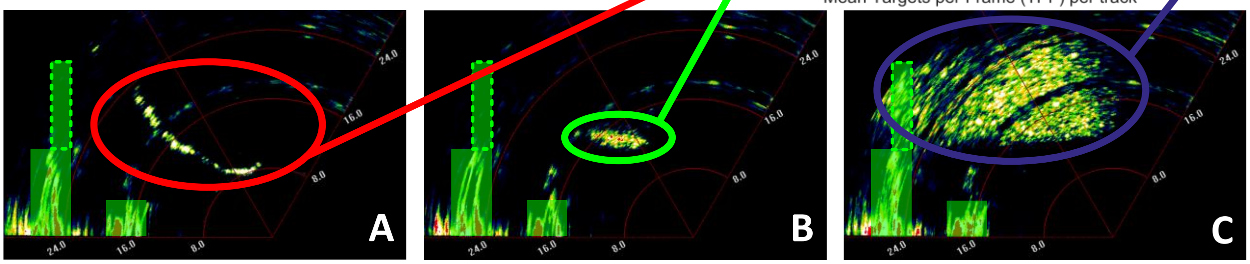
An intensity threshold is applied to filter remaining spurious and persistent reflections, caused by strong returns from the turbine structure inducing both radial and sector bands of noise throughout the water column. This threshold was set based on the typical target strengths measured at this site.

Each target is approximated by an ellipse and stored with a number of characteristics: the XY center, bounding ellipse area, ellipse ratio, and ellipse orientation. The target acoustic intensity is stored as the pixel "mass" (the sum of the intensities of all pixels comprising the target), coupled with the minimum and maximum intensity. The number of Targets Present per Frame (TPF) is also recorded. A dilation operation is used to parameterize fish shoals as a single object with a single centroid to ensure robust tracking of the *overall* movement of a fish shoal.

Target tracking uses a modified nearest-neighbor search, which seeks to establish a 1:1 relationship between all targets in the current frame to a maintained array of tracked targets. The closest (nearest-neighbor) target is corresponded if within a velocity threshold. A decay function is used to reduce the search area for each historical frame. This represents the increasing uncertainty in establishing a correspondence with every frame in which the target is not observed. If there are multiple, equally-likely corresponding tracked targets, then the most recently observed tracked target is selected. If a correspondence to a tracked target cannot be established, then a new track is started using the current target observation. Track maintenance uses a voting-out algorithm which allows targets to be momentarily not detected (for

FIGURE 3. THE MEAN TPF OVER A TRACK CAN BE USED TO CLASSIFY MULTIBEAM TARGETS INTO 'SINGLE TARGETS' (A), 'SMALL SCHOOLS' (B) AND 'LARGE SCHOOLS' (C). SINGLE TARGETS CAN BE FURTHER CLASSIFIED INTO FISH, DIVING BIRDS DISTINGUISHED BY THEIR CHARACTERISTIC U-SHAPED DIVE [13] AS SHOWN HERE AND MARINE MAMMALS CHARACTERIZED BY THEIR LARGE SIZE. EXAMPLE TARGETS ARE AVERAGED OVER SEVERAL SECONDS TO HIGHLIGHT MOVEMENT AND ARE FROM THE 2013 DEPLOYMENT ADJACENT TO THE ATLANTIS AK-1000 TURBINE STRUCTURE. THE TURBINE STRUCTURE IS SHADED IN GREEN, AND THE EXPECTED BLADE RADIUS IS OUTLINED BY A DASHED GREEN LINE. RANGES ARE IN METERS.





example if they are masked by other targets, have changed attitude, or momentarily moved out of the swath). If re-detected, the target can be correctly matched to the same track. The continuous track profile allows examination of behavior around the turbine structure, including turbine-interactions, sudden changes of direction (evasion) and predator-prey interactions.

Classification is guided by a series of key metrics and confirmed by manual quality control to ensure robustness and reliability of these initial deployments and to provide a 'training' dataset to confirm later development of fully-autonomous classification. Morphometric measurements (size, shape, mean backscatter and distribution of backscatter, number of TPF, target separation) and behavior (velocity, velocity relative to water column, directionality, vertical distribution and inter-target interaction) can be measured using the MBES, and classification performed by defining bounds for the various parameters. Figure 3 shows an example of MBES target classification using mean TPF.

MULTIFREQUENCY ECHOSOUNDER PROCESSING

High-energy MRE sites demanded a new approach to isolate ecological targets from the overwhelming backscatter due to turbulent physical dynamics. Custom MATLAB scripts were written for processing and analysis.

Surface removal is achieved by a line-picking algorithm based on a minimum threshold for surface volume backscatter strength (Sv). Precise distinction is difficult during energetic periods due to the disturbed surface and strongly reflecting aerated water near the surface. The optimal threshold over the changing conditions with minimal loss of data is selected using Otsu's method from the field of image-processing. This defines the optimal threshold to separate the probability distribution functions of classes of pixels in an image. The resulting surface range is tested by inspection and power spectrum analysis.

Adaptive processing preserves maximum sensitivity throughout varying turbulent conditions, which avoids false detection of ecological targets during regions of intense turbulence, yet without thresholding targets out during calmer periods. The basis is selective subtraction from a scale-sensitive smoothed background version of the data. A moving window median filter is used, of dimensions small enough to preserve resolution yet high enough to give appropriate statistical stability. The filter dimensions are tuned based on analysis of the typical scales of ecological targets and turbulence morphology. The median-filtered result is suppressed during areas determined to have high levels of Sv from turbulent processes which exceed a threshold. This approach stabilizes the data in depth and time, providing better performance of standard Sv and size thresholding target detection methods. As this approach is scale selective, any physical backscattering structures of a comparable scale to ecological targets will be preserved and so an additional filter is required. In particular, wind-wave generated clouds of air bubbles cause intense backscattering structures across all frequencies which extend in depth over much of the data. Such structures are

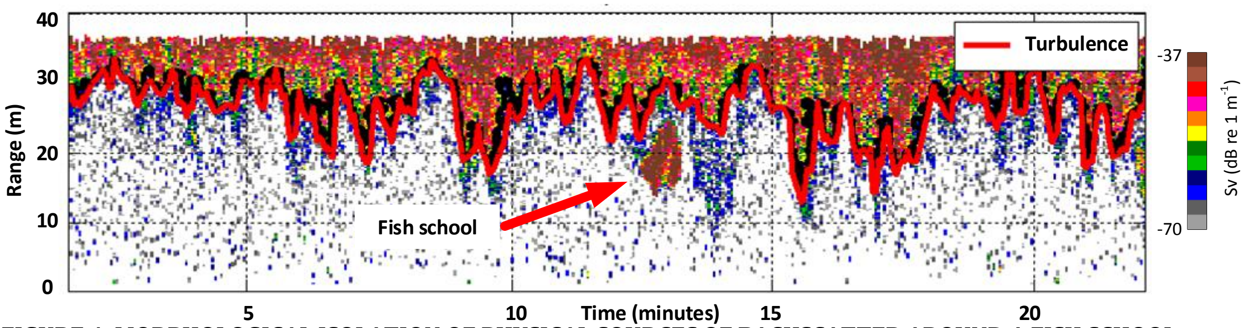


FIGURE 4. MORPHOLOGICAL ISOLATION OF PHYSICAL SOURCES OF BACKSCATTER AROUND A FISH SCHOOL.

morphologically isolated based on their connectivity with the sea surface and again an optimal threshold is selected to exclude the minimum possible data from further analysis. Tracing algorithms are used to delineate these intense physical backscattering structures from further target detection steps (Figure 4).

Target detection is then performed using Sv and size thresholds. A -55 dB re 1 m^{-1} threshold is used on the 200 kHz processed dataset with a minimum 10 pixel connected region to delineate a target boundary. This provides better performance at near-zero and very high velocities than the use of a minimum height and length dimensions in meters. The final processing step validates target regions using multifrequency characteristics; an optimal threshold for the mean Sv difference between frequencies is used to systematically reject regions corresponding to physical processes. Target classification then uses morphometric, target strength and multifrequency information.

CO-REGISTRATION

Co-registration between the MBES and EK60 adds certainty and robustness to the detection, tracking and identification of targets, but also allows targets to be described with information from both instruments (e.g. movement and behavior from the MBES, calibrated target strength, higher sensitivity and frequency response from the EK60). Co-registration of all targets is not possible, with some targets not seen on the EK60 due to the smaller detection volume, and some targets not seen on the MBES due to the lower sensitivity. Preserving targets detected on a single instrument, together with any co-registered targets provides the most complete dataset.

Co-registration aims to identify the same target on each instrument with an associated measure of certainty. This can be performed at a variety of levels. The simplest method seeks to establish a single nearest-neighbor match within a temporal and spatial threshold for targets observed on both instruments.

The next level incorporates trajectory. For example, if a target is moving through the MBES swath toward the EK60 beam, then its trajectory and time to next EK60 ping can be used to predict the target's path through the EK60, with an uncertainty based on vertical movement, directionality and time between observations.

The final level of co-registration incorporates target characteristics to aid establishing correspondences between targets detected on each instrument. This is useful in periods of high target density. However, metrics are not directly translatable between instruments and only approximate conversions can be used due to the different modes of operation, non-linear conversions and an uncalibrated MBES.

Figure 5 demonstrates temporal co-registration from the 2013 deployment next to the Atlantis turbine structure, combining behavioral MBES information with quantitative EK60 metrics.

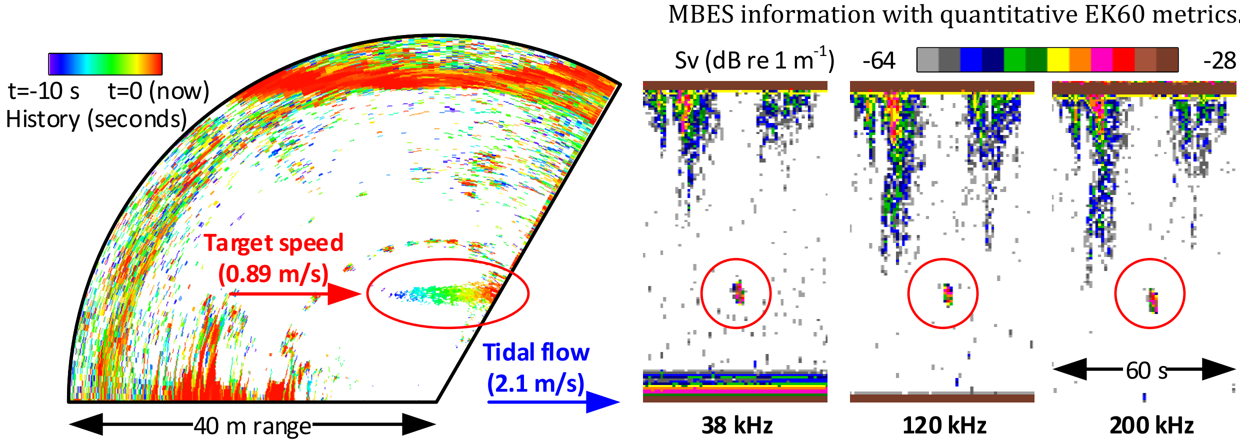


FIGURE 5. MBES AND EK60 CO-REGISTRATION OF A FISH SHOAL AROUND THE ATLANTIS TURBINE STRUCTURE.

CONCLUSIONS

Environmental monitoring in high-energy sites around MREDs has been demonstrated. The integration of a MBES and multifrequency echosounder provides information gains, including robust target tracking and behavioral observations (e.g. predator-prey interactions) with concurrent quantitative measurements of target size, distribution and morphology. Using this information, the depth preference and interactions of birds, fish schools and marine mammals with MREDs can be tracked. Seabird and mammal dive profiles, predator-prey interactions and the effect of hydrodynamic processes during foraging events throughout the water column can also be analyzed. These datasets offer insights into how fish, seabirds and marine mammals successfully forage within dynamic marine habitats and whether individuals face collision risks with tidal stream turbines. The results can be used to guide marine spatial planning, device design, licensing and operation, as individual devices are scaled up to arrays and new sites are considered. The combination of the sensor platform and analytical approach can help to de-risk the licensing process by providing a higher level of certainty about the behavior of a range of mobile marine species in high-energy environments. With a greater mechanistic understanding of how and why mobile predators use these high-energy areas for foraging at single demonstration scales, the predictive power of the outcomes may lead to a wider strategic approach to monitoring and a reduction in the level of monitoring required at each commercial site. These monitoring techniques are now informing the environmental monitoring program for the MeyGen Tidal Energy Project in Scotland, UK.

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