Tracking marine mammals around anthropogenic structures: development and application of a passive- and active-acoustic sensor platform

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With the increasing urbanisation of the marine environment, there are concerns about the potential impacts of man-made structures on marine animals. One major concern derives from the potential for physical injury to large marine species such as seals and cetaceans through direct contact with moving blades of tidal turbines. However, collecting data to quantify these risks is challenging and methods for measuring movements underwater and interactions with turbines are limited. Potential tools include a small number of cutting-edge technologies that are being used increasingly for research and monitoring; these include Passive Acoustic Monitoring (PAM), multibeam Active Acoustic Monitoring (AAM), and underwater video.

Over the past several years, we have carried out a series of hardware and software developments to provide an integrated multi sensor PAM/AAM/video system to detect, classify, and track small cetaceans and seals around tidal turbines. To obtain statistically useful sample sizes, data collection had to be continuous over periods of months. With data rates in the order 10 Mbytes/s and power requirements around 75 W, it was impractical do deploy a battery powered archival system (due to storage and battery limitations). We therefore exploited tidal turbine infrastructure for power and to stream data to shore via optical fibre for processing and data archiving. Real time data processing effectively reduce the total amount of data stored by 2 – 3 orders of magnitude; this which reduced the raw data collected over a 12 month period to manageable volumes.

The system was deployed on an operational tidal turbine in Scotland and, to date, has collected a total 10 months data. We present the technical details of the data acquisition and real time processing system, and initial results on marine mammal presence around the turbine. Further, we introduce preliminary designs being developed as part of a recently funded project to develop a new multi sensor marine mammal tracking system; this aims to be more cost-effective, practical to deploy and recover, and be capable of integration into a wider range of tidal turbine technologies for deployment around future tidal energy devices.

Acknowledgements
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Changes in species behaviour predicted around tidal turbines from before/after array information

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It is known that tidal stream environments attract marine predators, where strong currents (2 to 4 ms-1 or even greater) and high turbulence can predictably disorientate prey and potentially increase catchability. However, the exact mechanisms underlying variation in the use of tidal stream environments remain mostly unknown [1]. It is possible that predators adapt their behaviour to match prey distribution, which may respond differently to changes in the physical environment on a variety of time scales, including tidal, diel, and/or seasonal cycles [e.g. 2].

Studies have showed that the installation of tidal stream turbine structures can affect fish distribution, due to changes in near-field hydrodynamics (current speed and turbulence characteristics) through the removal of energy [3]. Thus, it is possible that marine renewable devices will alter marine predators' distribution either directly (changes in hydrodynamics and noise levels) or indirectly (changes in prey distribution).

To assess the ecological implications of marine energy developments, a thorough understanding of species space-use in these areas and ecological interactions influencing their behaviour is crucial but it is currently lacking, mostly due to sampling difficulties due to strong currents.

In this project we have used simultaneously collected data on predator, prey, noise and hydrodynamics to explore the mechanisms that drive species behaviour and have identified key attributes that are acting as potential 'driving factors', such that predictive models can be built for a range of important predators (marine mammal and seabirds) and prey (fish). A range of statistical models (GAMMs, RF, SVR, ARMA) were developed with this data in both 'before and after & with/without' conditions at tidal sites, including the EMEC tidal test site. Prey distribution and a range of hydrodynamic variables including noise were incorporated into the model as explanatory variables. This project's use of models to predict the level of changes of both predator and prey behaviour and predator-prey interactions (foraging events) with the addition of tidal developments using environmental variables can be used to develop future monitoring, operational modifications, as well as detecting threshold conditions which can be used for mitigation efforts.

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3D imaging of marine epifauna: towards an ecosystem understanding of artificial reefs

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Sessile epibiota rapidly colonise offshore man-made structures, in turn attracting mobile invertebrates, fish and top predators. These 'artificial reef' communities can deliver ecosystem services, including water filtration, carbon sequestration and provision of fisheries (sport and commercial). Colonisation of structures has been studied at local scales, but the role of artificial reefs in regional processes and ecosystems, where structures may constitute a significant proportion of total hard substrata, is poorly understood. The increasing dominance of man-made structures in marine ecosystems, termed 'ocean sprawl', may have profound effects on ecosystem processes including the consumption and production of plankton and the spatial distribution of fish, mammals and birds.

Quantifying the interactions between structures and regional-scale processes, including the value of structures to recreational/commercial fisheries, requires an ecosystem modelling approach, which can capture the biomass flux and behaviour of mobile fauna. To provide meaningful outputs, ecosystem models (EMs) require detailed and accurate parameterisation, and a profound understanding of trophic linkages. Benthic organisms typically occupy low trophic levels, and they play a pivotal role in marine food webs and the delivery of key ecosystem functions. Owing to limitations in input data, particularly for benthic data, EMs have yet to be applied, to full effect, for quantifying the consequences of offshore structure commissioning and/or decommissioning. Obtaining data to parameterise EMs (e.g. estimates of epibiota biomass and secondary production) has previously been limited by the time and cost constraints of conducting offshore ecological surveys at the necessary spatial and temporal scales.

In many oceanic basins, offshore oil and gas (O&G) and wind operators use standardised procedures to collect video footage with remotely operated vehicles (ROV) for maintenance purposes. The value of this footage, collected over wide spatial and temporal scales, has been recognised for biodiversity assessments, and industry videos have been used to identify associations between O&G infrastructure and commercially-exploited and protected species. Structure from Motion Photogrammetry' (SfMP) is a revolutionary image processing technique that enables spatially-referenced 3D models ('images') to be generated from standard 2D photographic source material (e.g. video-frames). Recent advances in SfMP means that it is now possible to use ROV footage to generate 3D images, from which estimates of the volume and biomass of sessile marine fauna can be derived.

This presentation will showcase the generation of 3D-images of benthic fauna using standard ROV footage of North Sea infrastructure. We will demonstrate the technical and logistical challenges of applying SfMP to industry footage (including issues of scale determination and water clarity) and provide a series of recommendations on 'best-practice' ROV survey techniques for the 3D image generation. Species-specific calibrations for converting SfMP-derived volume estimates of common North Sea benthic fauna into biomass will be also presented.

These novel imaging techniques, which are both transferable to other geographical regionals and scalable to large infrastructure arrays, offer unprecedented potential to generate empirical data on the biomass and productivity of epibiota associated with offshore structures at local and regional levels. These data can then be used to parameterise EMs, and ultimately improve our understanding of the ecosystem-scale consequences of installing and removing artificial structures

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Artificial reef creation using decommissioned pipeline protections – analysing industry ROV footage to quantify benthic and fish assemblages.

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A significant proportion of North Sea oil and gas installations are rapidly approaching the end of their operational lifespans (Ahiaga-Dagbui, 2017). Industry is now faced with the challenge of removing oil and gas platforms, subsea infrastructure, pipelines and pipeline protections from service (decommissioning). Within the North Sea, approximately 200 platforms and 7,800km of pipeline are forecast to be decommissioned between 2017 and 2025 (Oil and Gas UK, 2017). Many of these pipelines exhibit some form of pipeline protection that serve to safeguard pipelines from possible damage due to dropped objects, collisions with trawled fishing gear and hydrodynamic forces. The protections include rock dump, grout bags and concrete mattresses, all of which need to be accounted for in the decommissioning process.

With increased decommissioning activity, the potential re-use or recycling of structures is becoming a major priority for operators and policy makers in an effort to conduct the decommissioning process in the most environmentally, economically and socially beneficial way. The use of oil and gas installations as artificial reefs has become a viable option in other areas of the world for decommissioning with rigs to reef programs gaining success in the Gulf of Mexico (Macreadie, 2011). However, very little is known about the artificial reef creation potential of pipelines and their respective protections. In order to understand how pipelines and protections could function as artificial reefs, and provide environmental benefits, we need to know to what extent the structures provide habitat to marine species and the differences in species between different structure types, at different depths and between different regions of the North Sea.

Using high definition ROV footage obtained from integrity surveys, interactions between North Sea pipelines, benthic fauna and fish were quantified. Different structures were seen to host different species of fish with concrete mattresses playing host to larger assemblages of *Pollachius pollachius* and *Sebastes sp*. While rock dump was seen to host larger populations of *Gadoid sp.* overall and also hosted species not seen on concrete mattresses (*Lophius sp.* and *Anarhichas lupus*). Concrete mattresses exhibited larger numbers of adult stage fish in comparison to rock dump where juvenile stage fish were more prominent. In terms of benthos, concrete mattresses exhibited larger populations of *Asteroidea sp*. whilst rock dump hosted larger populations of *Actiniaria sp.*

These results provide new insights into potential repurposing of pipeline protections and contribute to an evidence base to industry and policy makers for decision making in the decommissioning process.

Acknowledgements

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Evaluating the effects of man-made structures on the functioning of the benthic system in the North Sea

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Over the last decades, the rapid expansion of man-made structure (MMS) in the marine environment has generated increased attention by industry, scientists and legislators. In the North Sea, these structures, ranging from oil and gas platforms, buoys, wrecks to wind turbines, offer additional artificial hard substrates over predominantly soft-sediment areas. MMS in shallow shelf seas are expected to modify benthic communities over various spatial and temporal scales with potential repercussions for overall ecosystem functioning.

Our investigations on large offshore structures have identified a suite of unique detectable effects ranging from biodiversity changes with repercussions on local ecosystem functioning to the provision of habitat for fouling communities, acting as stepping stones and many other ecological modifications. Consequently, MMS might induce structural, functional and process-driven changes, which are different from those expected in natural soft bottom benthic systems.

This study considers soft-sediment and introduced hard-substrate epifouling communities. The combination of these systems provides a unique ecological opportunity to ascertain biodiversity changes triggered by loss and gain of species provided by the addition of MMS. Our understanding on how ecological functioning might be altered by the addition of these MMSs is still in its infancy. The approach taken within the scope of this work aimed at evaluating functional changes with a combination of biological traits analysis tools and energy flow changes calculated via estimated secondary production and trophic web modelling tool (Ecopath with Ecosim). Further, our study compared the different types of introduced MMS among the natural soft sediment communities, disentangling how the ecological functioning of the macrobenthos may be altered by the introduction of these structures, which provides improved concepts for current monitoring assessments.

The influence of oil and gas infrastructure in Australian marine ecosystems: informing decommissioning decisions

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The influence of oil and gas infrastructure in Australian marine ecosystems: informing decommissioning decisions

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Oil and gas infrastructure is widespread throughout many of the World's territorial seas and the resource-rich north-west shelf of Western Australia is no exception, with thousands of kilometers of pipeline linking extraction and processing facilities. Increasingly, offshore infrastructure is reaching the end of its productive life and faces decommissioning. Knowledge of the ecological role of infrastructure is required to inform on the 'best' option for decommissioning. We use specialised high definition stereo-video systems and ROV inspection video collected by industry to assess habitats and the diversity, abundance and biomass of fish on wells, pipelines and platforms across the north-west shelf of Western Australia. Potential new species, range extensions and new behaviours are being observed around oil and gas infrastructure in this remote, region of the world. Important commercially fished species are present in higher abundance on pipelines than in surrounding areas and display diurnal patterns of infrastructure use. Habitat type and complexity, in addition to infrastructure type, position and depth, influence fish abundance and diversity across the shelf. Using video imaging techniques, our research provides insight into the ecological role of offshore infrastructure and provides new knowledge to inform decommissioning decisions.

Does oil and gas infrastructure create ecologically coherent networks of iconic British species? The ANChor project and beyond.

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The INfluence of man-made Structures In The Ecosystem (INSITE) project *ANChor* (2016-2018) investigated the potential for oil and gas infrastructure to enhance connectivity of several species including protected cold-water corals threatened by human pressures and climate change. Biophysical dispersal models simulated potential connectivity between North Sea infrastructure and metapopulations downstream. *ANChor* illustrated how just a single generation of "virtual" larvae of an iconic, protected species cold-water coral released from this infrastructure could potentially create a connected anthropogenic system, with larvae becoming competent to settle over deep-sea, shelf and fjord coral ecosystems including a marine protected area. *In situ* footage and coral samples from structures confirm radically different coral ecosystems from those reported two decades ago: today, coral heads and morphology have reached proportions approaching those of natural populations and even host the same coral symbionts, similar to natural coral ecosystems in both structure and function. Today, *ANChor*'s legacy aims to progress this science through frontier collaborations with industry, saturation dive teams and remotely operated vehicle surveys to ground-truth simulations, collect samples for genetics and biodiversity research and plan *in situ* missions. *ANChor* was the first study showing that a system of anthropogenic structures could have trans-national conservation significance to an iconic British species by creating ecologically connected networks and by acting as stepping-stones across geopolitical boundaries to natural populations. Has this long-standing built environment left a similar legacy on other iconic British species like sharks, seabirds and marine mammals?