Understanding Near Field Evasion Behavior as a Component of Collision Risk with Tidal Turbines Through the Analysis of Video Footage

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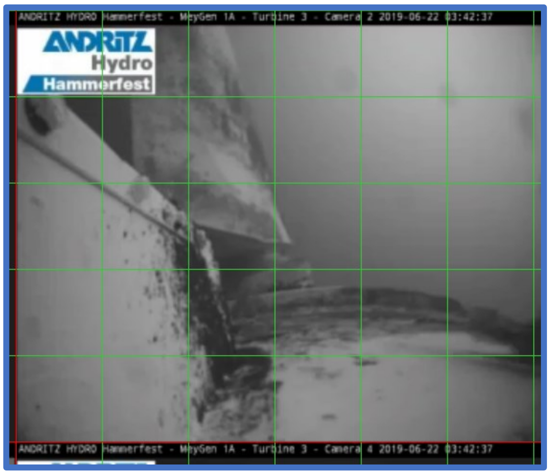

Tidal turbine energy arrays are currently at the demonstration scale with large scale projects likely in the near future. Collision risk between marine fauna and these submerged turbines is a key environmental impact that is currently being assessed as part of the EIA process before moving forward. This study utilised video footage from the MeyGen turbines located in the Pentland Firth to investigate near field fish behaviour to inform this collision risk analysis. Time of day, tidal rotation, flow rate and blade rotation speed were all factors investigated. This will also contribute to the development of underwater video footage analysis and subsequent modelling methodologies.

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Do electromagnetic fields from renewable energy subsea power cables affect the righting reflex or physiological responses of coastal invertebrates?

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The effects of anthropogenic Electromagnetic Fields (EMFs) on marine species is an emerging field of research due to the rapidly increasing number of subsea electrical cables from offshore Marine Renewable Energy Devices (MREDs), which are known to generate EMFs. This increase in subsea cables is taking place globally; yet, significant gaps exist in the current knowledge of the effects of EMFs on marine organisms. This area of research has been identified as a high priority by various stakeholders, including Scottish Marine Energy Research (ScotMER), part of the Scottish Government (The Crown Estate, 2019).

This study investigates the effects of a 24-hour exposure of simulated 500 µT EMF (modelled for landing cables buried under 0.25 m rock (Moray Offshore Renewables Ltd, 2011)) on the righting reflex (i.e. ability to correct or 'right' their position) of four coastal marine invertebrate species: common starfish (*Asterias rubens*), European edible sea urchin (*Echinus esculentus*), velvet swimming crab (*Necora puber*), and common periwinkle (*Littorina littorea*). Haemolymph or coelomic fluid was also taken for analysis of common stress markers.

EMF was not found to significantly affect the righting reflex, refractometry (protein concentration), or Total Haemocyte Count (THC) of any of the species tested. Starfish and urchin righting reflex datasets were robust, whilst velvet crab and periwinkle datasets give a good first result, as righting reflex times have never been studied with regards to EMF exposure and coastal species.

Improving our understanding about the effects of the EMFs generated by the renewables industry on ecosystem components is vital for the development of Marine Spatial Planning and sustainable exploitation of resources. In addition, the produced knowledge facilitates the implementation of the ambitious Marine Strategy Framework Directive (MSFD) which specifically addresses the introduction of energy in the marine environment, and ultimately serves the achievement of Good Environmental Status.

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Potential auditory impacts from piling on cetacean species on the east coast of Scotland, and how mitigation can reduce the effects of impulsive noise.

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Marine renewable developments have started to raise concerns over the potential impacts of underwater noise on marine species, more recently from pile-driving activities from offshore wind farms. Recent studies have identified frequencies at levels that could cause potential long-term impacts on health, therefore, this study was conducted to assess the potential impact of a planned offshore wind farm off the coast of Angus to contribute to this new area of science. We know that pile driving generates low-high level impulsive frequencies underwater, however, there is still a lack of understanding of how these impact marine mammals across different hearing thresholds. In this study, frequencies were modelled using a two-dimensional ray-tracing-based underwater acoustic model and were used to assess the risk of TTS and PTS levels. The modelled SEL levels when compared against the hearing threshold classifications of Southall et al. and the NOAA, with findings, suggesting that there is a potentially higher risk of TTS levels across all cetacean groups, with specific emphasis placed on cetaceans such as Bottlenose Dolphins (*Tursiops truncatus*) and Harbour Porpoises *(Phocoena phocoena*). Potential impacts were discussed within this study, revealing the auditory and behavioural risks associated with long-term exposure to excessive SEL levels. In addition, mitigation technologies and policies were examined, with modelled Bubble Curtain scenarios revealing reductions in SELs by around 8dB, demonstrating how NAS technologies can influence the propagating sound. These findings overall highlight the probability of certain cetacean species and concluded examples of measures that could offer the most promising long-term solution to deliver existing and future policies to manage increasing levels of underwater noise pollution.

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Monitoring animal behaviour around marine renewable energy sites

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With rising interest in marine renewable energy (MRE), the complex interplay of MRE device placement and subsequent changes to animal behaviour needs to be assessed to minimise potential impacts and allow stakeholders, regulators and policy makers to make informed decision for future developments. Through use of multibeam echosounders (imaging sonar) we can observe and record animal behaviour at a fine scale (metres, seconds) drawing comparisons, establishing patterns and evaluating potential changes around MRE sites.

Being able to properly account for the impact MRE devices might have on the animals that utilise tidal-stream environments has been a major undertaking of marine scientists around the globe. Attention has been paid mainly towards the potential for collision risk and the introduction and increase of marine noise and its corresponding impact on marine mammal behaviour [1, 2]. Additionally, changes in fish school behaviour around MRE devices have also been observed [3]. Advances have been made in understanding animal responses, but the lack of quantitative data, which is locked behind terabytes of recorded raw multibeam data, have limited definite and time-efficient proof and advice for stakeholders or environmental agencies in many cases.

This PhD project aims to examine the factors that influence the visibility of animal targets within a multibeam recording and to investigate the usefulness of evaluating animal behaviour through existing datasets recorded by low-resolution / low frequency multibeam instruments. It aims to increase the understanding of this complex interplay to be able to make informed decisions about the potential effects MRE device placement might have on animal targets as a whole instead of focusing on specific subgroups.

Preliminary results investigating the visibility of a standardised target and the analysis of low resolution/frequency multibeam data will be presented.

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Do avoidance/attraction responses of kittiwakes from the same colony vary between different offshore wind farms?

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Offshore wind farms play a key role in achieving government pledges to reduce greenhouse gas emissions, but our understanding of how they impact marine life such as seabirds is still lacking in some regards, i.e. through influencing movements. Collision risk models (CRM) are a major part of ornithological environmental impact assessments required for new developments. Outputs of these models are sensitive to input parameters, which includes avoidance rate; an estimate of the proportion of birds which actively avoid collision (Band 2012). Recent studies have used tracking data to compare observed versus expected values of presence within defined areas around turbines and wind farm perimeters (Schaub et al. 2019, Johnston et al. 2022) to determine avoidance responses, with the ability to represent both attraction and avoidance ("Avoidance/Attraction Index" or AAI). Such empirically-based knowledge may help to increase confidence in CRMs.

We used tracking (GPS) data to quantify the AAI of black-legged kittiwakes (*Rissa tridactyla*). A species with widespread declines in population (Birdlife International, 2019) and at risk of collision with wind farm turbines (Furness et al. 2013, Cook et al. 2014). There are three relatively small wind farms (5, 6, and 11 turbines) within the study colony's (Whinnyfold) home range during the breeding season. This provided a unique opportunity to detect potential differences in responses to different wind farms. This was conducted on two spatial scales; (i) "macro-response" which compared 1 km buffer zones extending to 4 km from wind farm boundaries, and (ii) "meso-response" to look at responses on a sub-kilometre (0-200 m) scale which can provide insight into responses to individual turbines.

Preliminary results indicate a trend towards attraction to the wind farm boundary within 0-2 km, and avoidance at 2-4 km away when analysing for separate wind farms. This pattern was not detected when the whole dataset was analysed for all wind farms combined. Meso-response is currently being analysed. Initial results indicate that current avoidance rates used for CRM may be too simplified as responses can vary depending on which wind farm is encountered. Studies like this are important as the proliferation of wind farms in the marine environment will result in many seabird colonies having multiple wind farms within their home ranges, thus contributing to our understanding of their potentially cumulative impacts.

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Exploring the effects of electromagnetic fields on diatoms in multi-stressor environments

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In the face of unprecedented climate change, our ability to predict how real ecosystems could evolve in the future is largely limited by the complexity of natural ecosystems which, unlike simple laboratory environments, comprise multiple environmental drivers acting simultaneously. Multiple stressor research across study systems has highlighted the roles of ecological complexity and temporal factors in shaping organismal response. Within the context of phytoplankton, multiple stressor studies have especially leveraged the power of experimental evolution and factorial experimental designs to understand both immediate and long-term responses across combinations of stressors. These studies have primarily focused on climate change relevant stressors (such as temperature, nutrient availability, elevated CO_2, and acidification) and have also incorporated projected future climate values[1,2]. However, environmental changes encountered by phytoplankton, beyond a changing climate, include stressors stemming from renewable energy infrastructure—such as coastal windfarms. Electromagnetic radiation (EMF) generated at windfarms and around power cables has been shown to have wide-ranging effects across organisms and, in phytoplankton, is suspected to influence voltage-gated Ca^{2+} channels. In diatoms, a globally distributed phytoplankton that is integral to coastal ecosystems, Ca^{2+} signalling acts as part of a paracrine signalling pathway in response to stressors such as elevated temperatures, extended dark periods, and osmotic stress[3]. It then follows that, when occurring in conjunction with other abiotic stresses, EMF can interfere with this signalling mechanism and can potentially constrain the efficacy of protective plastic responses in diatoms. Exploring this question through short-term ecophysiology experiments and through evolution experiments will allow for a fuller understanding of diatom responses to changing coastal environments and will help ensure that responsible solutions to the climate crisis are being deployed.

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Assessing health change over time of a cold-water coral reef by examining the relationship between live and dead components of coral colonies and biodiversity

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The three-dimensional structure of cold water corals (CWC) results from an interplay between coral biology and environmental conditions and is essential for the fauna in these ecosystems (Roberts et al., 2009; Henry et al., 2010; Buhl-Mortensen et al., 2010). In this study, species diversity in the Norwegian Tisler Reef were measured along with colony size and the proportion of live and dead skeletons of *Lophelia pertusa* colonies using video recordings from ROV (Remotely Operated Vehicles) transects. The main objective of this work was to investigate the monitoring method used to quantify coral growth by Vad et al. (2017) and its potential in combination with biodiversity analyses as a tool to assess the health of these habitats over time. A total of twenty-one colonies from 2014 and 2021 were selected, the live and dead layers were measured, and their ratios determined and analysed. The correlation of changes in biodiversity with changes in layer ratios over the years was then investigated. The work demonstrates that: (1) no significant changes in the ratio of live to dead colonies between years were found; (2) however, it was possible to confirm the observations of Vad et al. (2017) that the ratio of live to dead layer correlates negatively with the total size of the colony and that the size of the live layer correlates positively with the total size of the colony; (3) the analysis of biodiversity showed a shift in species diversity and their community structure between years and according to the correlations of the layer ratios. This led to the hypothesis that the Tisler Reef in 2014 was previously or at that time in a state of stress; and (4) shows that the monitoring method of Vad et al. (2017) combined with biodiversity analysis can provide more insight into the nature of changes in a coral reef and its health. These results suggest that as the growth rate slows due to environmental stressors, the development of a colony can also have an impact on the biodiversity in its ecosystems. The weakening of the dead coral skeleton, which is threatened by the flattening of the aragonite saturation horizon of the oceans and the associated acidification of the deep sea (Hennige et al., 2020), may have significant implications for the future integrity of the deep-sea reefs and their biodiversity, which depend on these habitats. Comparing changes in biodiversity with the alteration of the clearly visual white (living) and grey (dead) parts of the colonies offers a new way to monitor these ecosystems over time and estimate their changes.

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Listening Lines: Assessing the Feasibility of Deploying HydroMoths on Static Fishing Gear to Monitor Cetaceans

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This study aims to assess the feasibility of deploying HydroMoths on static fishing gear to collect acoustic data for the purposes of monitoring cetaceans. In the UK, there are national and international policy frameworks which require for species of cetaceans to be monitored in order to evaluate their environmental status and to examine the risk of anthropogenic threats towards them[1–4]. Passive Acoustic Monitoring (PAM) is a commonly used methodology for monitoring cetaceans[5–7]. However, expensive equipment and operational costs can create a financial barrier for acoustic research, therefore there is a need to make underwater acoustic recording devices more financially accessible[5,8]. The HydroMoth is an underwater variant of the AudioMoth (Open Acoustic Devices) and is available for a fraction of the price of other commercially available underwater acoustic instruments[5,9]. In order to first test the capabilities of the HydroMoth, an ex-situ mesocosm experiment was carried out to assess the high frequency performance of the HydroMoth compared to a research grade acoustic instrument (SoundTrap 300 HF), and to test the directionality and gain level settings of the HydroMoth. A creel deployment was then trialed in field conditions off the coast of Berwickshire, South-East Scotland. The results of this study show it is feasible to deploy a HydroMoth on static fishing gear for the purposes of acoustic monitoring, which is supported by recordings of dolphin whistles and boat engine noise captured by the HydroMoth. However, our results also suggest the HydroMoth is not capable of detecting the high frequency signals used by some species of odontocetes. The results also imply sound source orientation can have an effect on the HydroMoths ability to detect signals, and different gain level settings can affect the quality of recordings captured by the HydroMoth. Further field research is needed to test the capabilities of the HydroMoth under different environmental conditions.

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Analyzing the Spatial Overlap of Potential Oil Spills in the Faroe-Shetland Channel and Predicted Deep-sea Sponge Grounds in the Northeast Atlantic and Subarctic Regions: Consequences and Ramifications for Conservation

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Deep-sea sponges form dense communities called sponge grounds that enhance benthic biodiversity and contribute to many ecosystem services including benthic-pelagic coupling (transfer of energy and nutrient from the seabed to the water column). While extensive sponge grounds have been discovered in Scottish, Icelandic, Greenlandic and Norwegian waters, the ecology of deep-sea sponges and their resilience and recovery potential to anthropogenic stressors remain largely unknown. Nevertheless, oil spills are a potential threat in regions where oil and gas exploration overlaps recognized sponge grounds, e.g., the Faroe-Shetland Sponge Belt Marine Protected Area located in the offshore waters of the Scottish waters of the Faroe-Shetland Channel (FSC) overlap with several oil and gas developments.

The present study examined the spatial overlap between a broad-scale ensemble species distribution model produced for the sponges in the Northeast Atlantic and Nordic regions and already available modelled oil spills at depths of 10-450 m, 500-950 m, and 1000-1500 m in the FSC. The ensemble model was estimated as the weighted average of three SDMs fitted to deep-sea sponge occurrence records obtained from the International Council for the Exploration of the Sea Data Portal using Maximum Entropy, Generalized Additive Model, and Random Forest algorithms (Ramiro Sánchez et al. 2019). The oil spill raster layers were digitized from the study by Main et al. (2017) that explored the potential extent of oil spills from a well blowout in the FSC at different water depths.

Sponge grounds were predicted in areas with a strong influence of currents and between bathymetric contours of 150-2000 meters in the Northeast Atlantic Ocean, the Celtic Sea, the North Sea, the Faroe Islands, Nordic Seas, and the Barents Sea (Burgos et al. 2020). All four models displayed good performance, but the Random Forest model performed the best based on the evaluation metrics, namely the Area Under Receiver Operator Curves. Depth, salinity, and dissolved oxygen were found to be the important environmental variables influencing the probability of sponge presence in the area. The spatial overlap analysis revealed that a potential oil spill in the FSC could impact sponge grounds between southern Iceland and the Reykjanes Ridge to Norway and the Barents Sea. The results of this project provide input to the conservation and spatial management of deep-sea sponges and contribute preliminary information to marine spatial planning (identify areas with sponge grounds for protection) and environmental impact assessments for oil and gas exploration.

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Investigating physiological and behavioural changes in commercially important Velvet Swimming Crab, *Necora puber* (L.), following exposure to Electromagnetic Fields (EMFs)

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The United Kingdom is one of the biggest developers of Marine Renewable Energy Devices (MREDs) worldwide[1] and it is committed to further expanding its offshore windfarms to hit the Net Zero emission target set to 2050. Numerous potential benefits arise from MRED developments, such as artificial reefs and spill-over effects, but these offshore structures have been shown to also cause significant impacts on the surrounding environment and marine wildlife. Electromagnetic field (EMFs) associated with underwater power cables are known sources of such impacts[2]. The effects stemming from EMF exposure are, however, currently poorly understood and there is no existing literature investigating the effects of this exposure on the commercially relevant velvet swimming crab, *Necora puber* (L.).

This study investigated the effect of different EMFs (500 µT and 1000 µT) on *Necora puber* by conducting physiological analyses and behavioural analyses. Changes in D – Glucose and L – Lactate concentrations in haemolymph and changes in shelter seeking behaviour during dual shelter trials were used as reliable stress indicators to quantify the effects of EMF exposure.

Analyses highlighted no significant changes caused by EMF exposure on *N. puber* physiology, both in D – Glucose and L – Lactate concentrations, while previous studies reported that dial patterns of these molecules were severely disturbed[3]. Analyses on behavioral effects did not report any significant difference in sheltering preference among the investigated treatment groups, contrasting with the literature, as most studies conducted on sheltering behaviours recounted attraction for EMF sources[3].

This preliminary study has important implications, as observed effects can be used to inform MRED developers and policy makers, allowing involved parties to make more informed decisions about mitigation strategies, EMF limitations, and other future offshore developments in the North Sea and worldwide. Further research on *Necora puber* and other marine invertebrate of commercial importance is however still needed to fully grasp the effects of electromagnetic fields on benthic communities.

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